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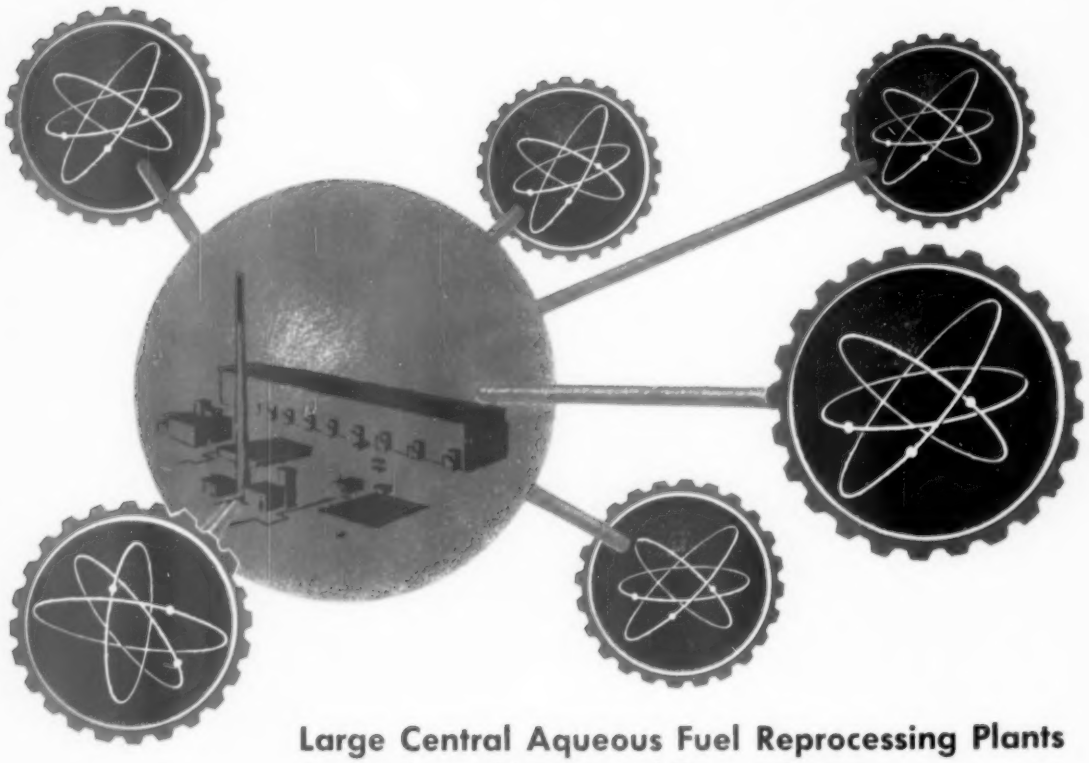
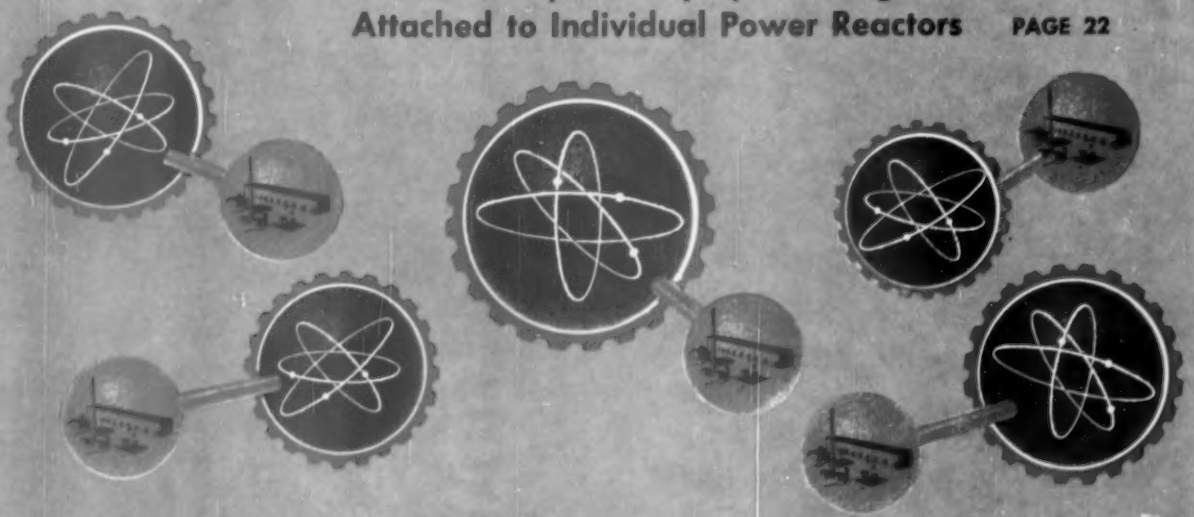


Large Central Aqueous Fuel Reprocessing Plants to Service a Number of Power Reactors

OR

Small Nonaqueous Pyroprocessing Plants Attached to Individual Power Reactors

PAGE 22



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NUCLEONICS

FEBRUARY • 1956

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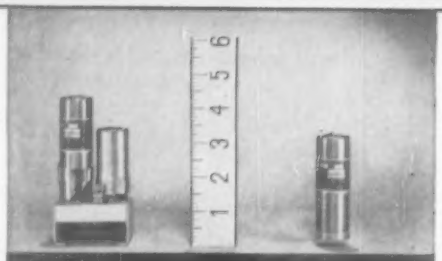

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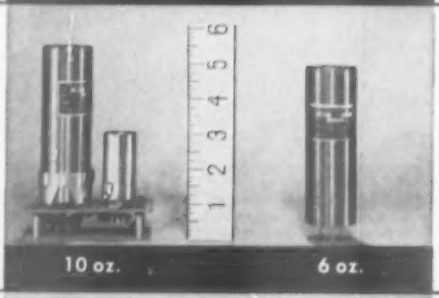

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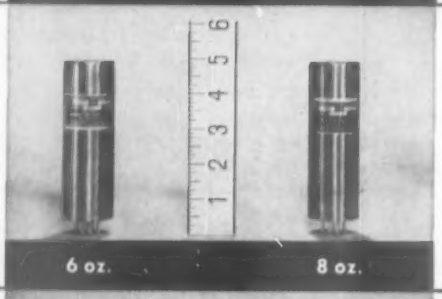

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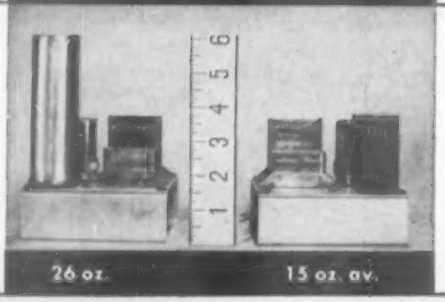

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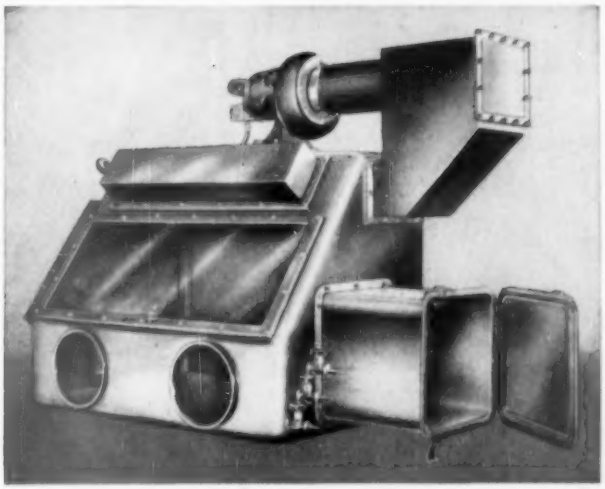

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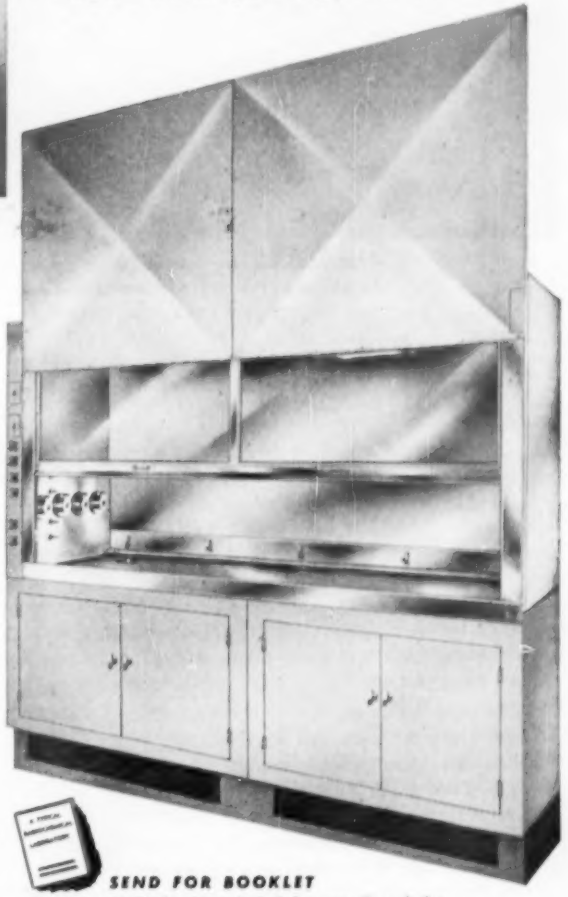

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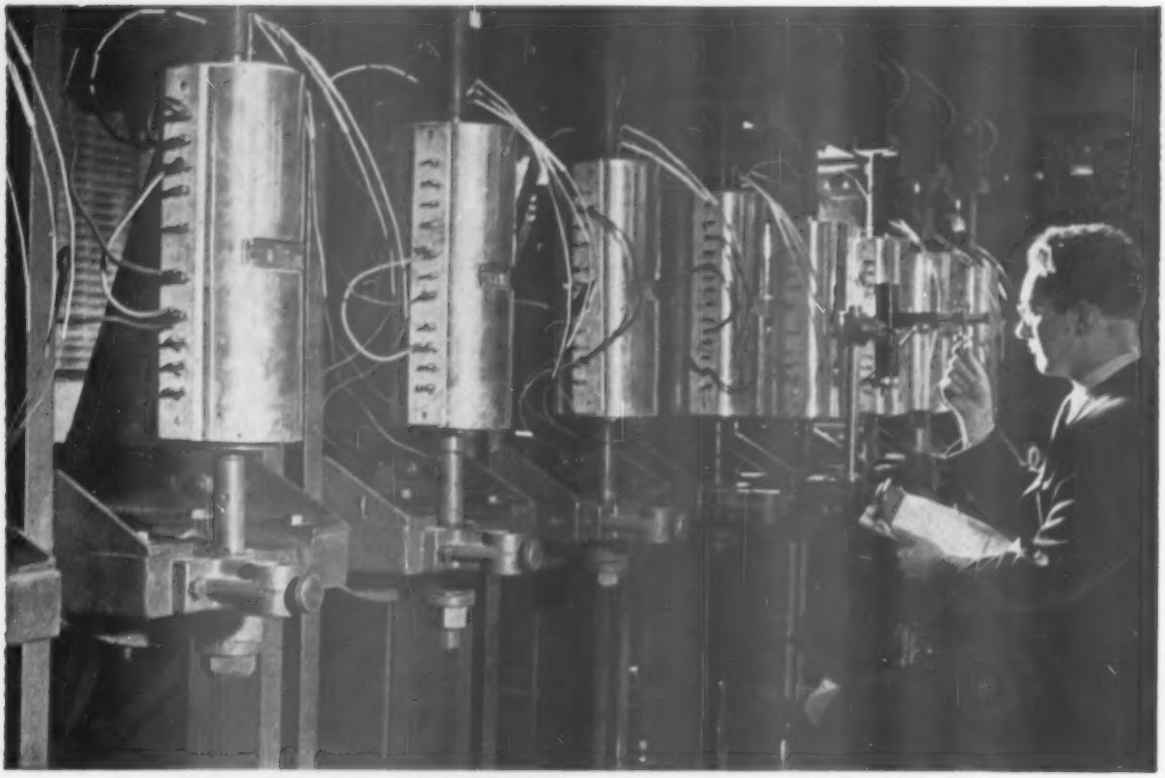

Creep tests under way in Inco's Research Laboratory. Here specimens of heat-resisting alloys are held under constant load at temperatures up to 2100°F.

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Complete information as to properties, fabrication and forms of this alloy is contained in Inco's 24-page Technical Bulletin T-7 "Engineering Properties of Inconel." It is yours for the asking.

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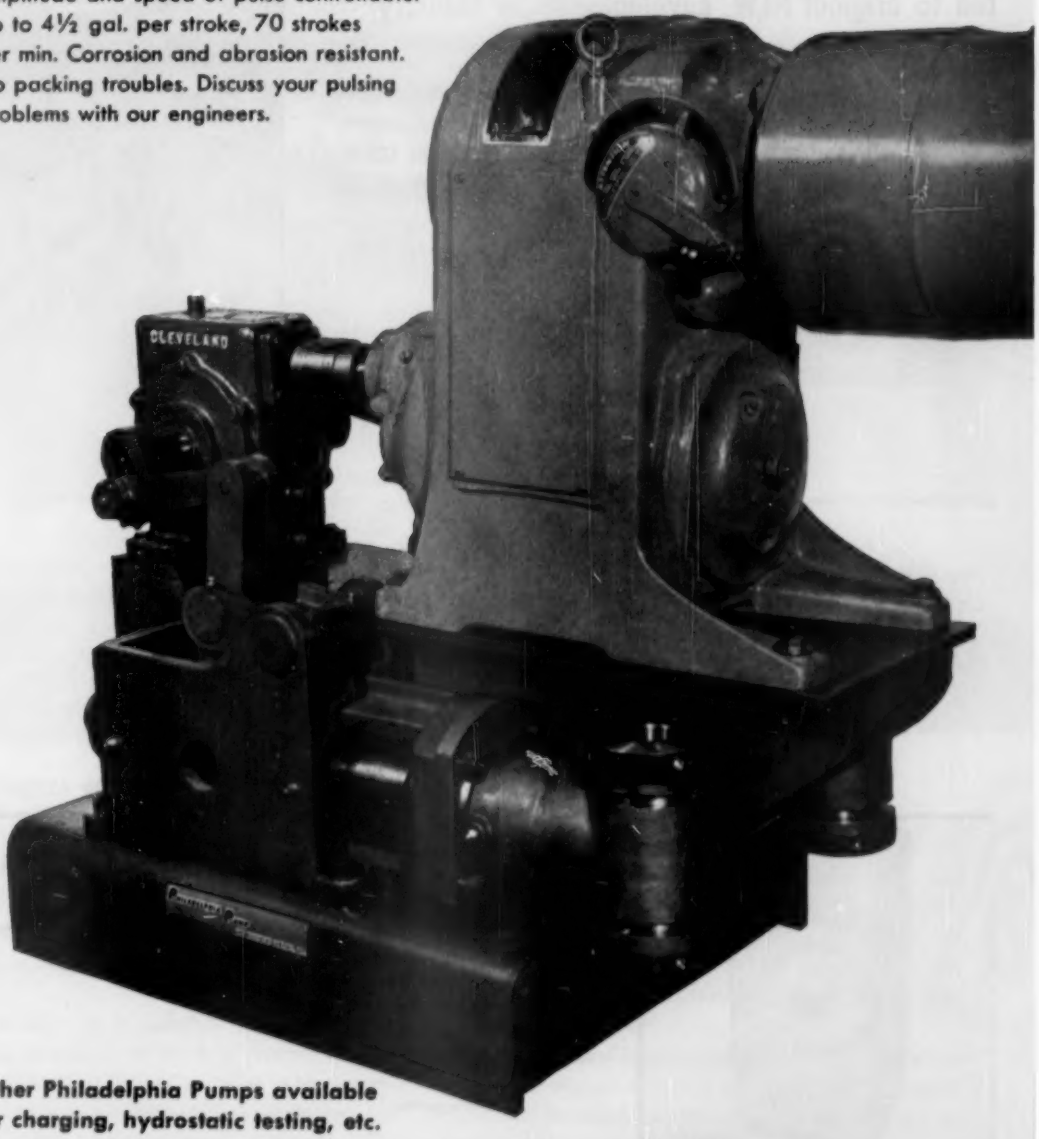

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REED-CURTIS was represented by invitation at the recent U.N.-sponsored Geneva Conference on the Peaceful Uses of Atomic Energy in the U. S. Technical Exhibit, and from October 19 until November 3 at the Carnegie International Center. Future exhibits will be announced.

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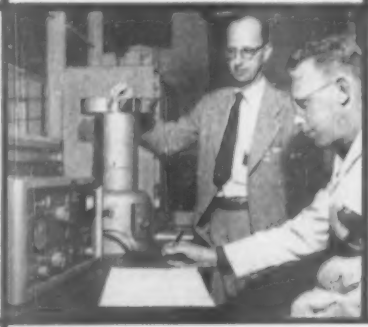

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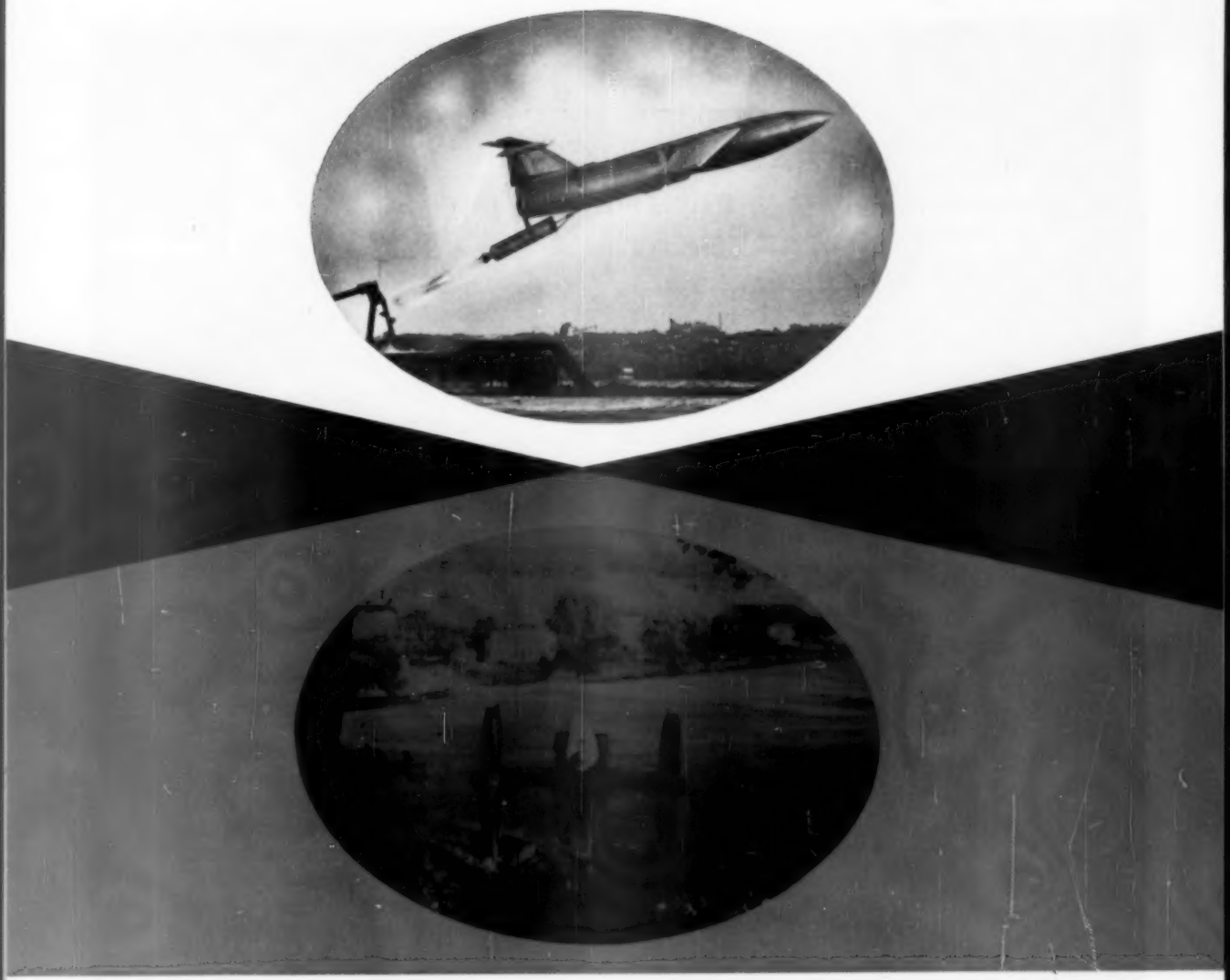


THE FORTUNES OF PEACE

America's first successful long-range pilotless bomber—the TM-61 Martin Matador—is a major weapons system conceived and developed in peacetime. And it is helping to keep the peace in an important way.

For the Matador is in quantity production, and already widely deployed. As the first aircraft having complete interchangeability of parts, it is transportable by air and can be delivered unassembled for stockpiling in critical outpost areas.

The new engineering concept that produced the Matador has already revised many design and production standards in the aircraft industry. For this versatile weapons system is being produced at the lowest cost-per-pound for comparable production, despite performance requirements more severe than those for most piloted aircraft.

Today, the new Martin engineering concept is revising the calendar on some of the most advanced flight and weapons systems projects now in the research and development stages.

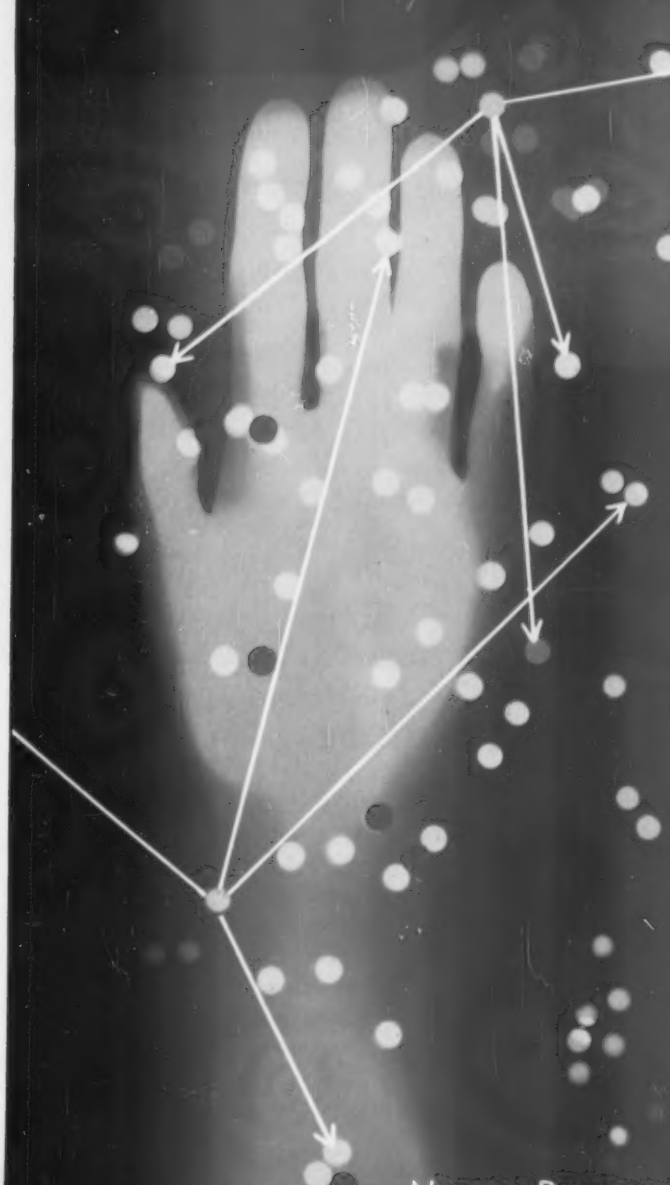
These are among the Fortunes of Peace!

MARTIN
BALTIMORE

NUCLEAR DEVELOPMENT CORPORATION OF AMERICA

HOW WE MEASURE A REACTOR'S FIRST HEARTBEAT

NDA_



A new reactor is conceived in a human imagination but it is born and is first alive as a "critical assembly" in a "critical" facility. Each reactor must undergo many exhaustive tests to establish safety and performance characteristics. The first such tests are conducted in a reactor critical facility at zero power under the direction and control of a skilled team of nuclear scientists, engineers and supporting technical personnel.

NDA is completing the country's first private industrial reactor critical facility at its Nuclear Experimental Station in Pawling, New York. Staff personnel are organizing and planning reactor critical experiments in connection with several reactor development programs under way at NDA.

NDA would be pleased to work with other reactor designers and builders in developing and conducting test programs utilizing this new reactor critical facility. Consultations on a program to meet your requirements are available without obligation.

NDA always welcomes inquiries from scientists and engineers interested in joining with us in this expanding field.

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

The McKinney Report

Last week the long-awaited McKinney report with its closely-guarded conclusions was out. The recommendations were neither as bold or as forceful as some had hoped, nor as limp as some had feared. The basic overall conclusion, answering the basic question the nine-man citizens' panel had been named by the Joint Committee on Atomic Energy to study (What impact will atomic energy have on our economy and industry?) was reassuring: atomic energy may have some transitional dislocating effects in some sectors of the economy, no seriously disruptive ones. The demand for energy will increase so steeply that all the power both fossil fuels and atomic energy can produce will be needed. The report sees 1965 as the earliest time at which atomic power is likely to become widely competitive in the U. S. Recommendations include:

Insurance. Biggest surprise was a negative recommendation: no Federal aid. "Implications that the Government is prepared now to take on the insurance burden might stifle vigorous private efforts to meet the problem. We look on a Federal atomic-insurance program as a threat to private atomic enterprise, not a benefit. It is a last resort not yet called for, one which may not be needed."

Foreign Aid. Most imaginative recommendation: a broad program of stepped-up U. S. aid to our "bilateral partners" for atomic power development and installation abroad, with a goal of "installation of at least 1-million kw of atomic generating capacity outside the U. S. as soon as possible—we hope by 1960." To set realistic goals in specific countries, the U. S. should "promptly convene a series of regional conferences." "The attention of the world should be called to the fact that such a program would parallel and possibly exceed the capacity installed during the same period at home." However this section also contains, some feel, the report's least forward-looking recommendation: the foreign aid program should require reprocessing of spent fuel in the United States.

Reactor development. "In the event that industry does not take on the full risks and burdens (of developing atomic power to the point where it can be used effectively and widely on a competitive basis), AEC should support a high-priority program (to do so) even to the construction with public funds of one full-scale 'demonstration' plant of each major reactor size and type." By "each major size," Panel Chairman Robert McKinney explained, was meant above 60 Mw and below—a distinction based on power plant sizes of large interconnected utilities and those for purely local use. He told NUCLEONICS he felt this program could very well be dovetailed with the foreign reactor aid program: "That would be an economical way of doing it," he said.

Medicine. Additional research centers with reactors and other equipment should be created; "low-cost atomic medical equipment suitable to the needs of the 6,100 hospitals and clinics without atomic facilities" should be designed.

Food preservation. "Radiation preservation of food does not appear likely to replace other methods to any substantial extent in the foreseeable future. When economically feasible, it would be a supplement to other methods."

Space heating. "Unlikely to prove economically competitive on any substantial scale." Process heat could become significant; private research should be encouraged.

Patents. "Complete review of the patent provisions of the 1954 act by the Joint Committee should be set aside until the expiration date of the compulsory licensing provisions—Sept. 1, 1959—is closer at hand. There are many other important policy issues which require more prompt attention."

Ownership of fissionable materials. JCAE should establish "continuing review" of the 1954 act in anticipation of permitting private ownership of special nuclear materials, at present expressly forbidden.

Information. AEC should "remove all reactor technology from the restricted category, including fuel element fabrication and processing techniques, leaving specific military applications to be protected by the defense classification system"; the dual AEC and Defense classification systems should be abolished, a single information control system set up; AEC should compile both classified and unclassified data on peaceful uses on a continuing and current basis for ready reference; the concept that information is "born" classified should be restricted to weapons data. Price schedules on fissionable materials should be declassified. On controlled fusion, the report called for "maximum interplay of scientific and engineering ideas" but stopped short of urging declassification. In this connection, the report for the first time put AEC on record as stating there is a military aspect to fusion power. It quotes a letter from Chairman Strauss replying to a request from Senator Anderson for AEC's views on the legal basis for classifying data on fusion power; the reply says "it appears that any thermonuclear reactor will be a substantial neutron producer capable of producing substantial quantities of special nuclear material. Hence it is our opinion that (such data) falls within the definition of 'restricted data' in section 11(r)" of the 1954 act. But the report revealed an AEC decision to give fusion power data to Q-cleared access permit holders with a need to know.

The Joint Committee, which this year will base its hearings on the state of the atomic energy industry on the McKinney report, will hear AEC leaders the week of Feb. 7, industry the next week.

Strauss on Secrecy Earlier, AEC's chairman last month journeyed to the home town of his severest critic on AEC secrecy, to make his riposte. Replying to Senator Anderson's recent attack (NU, Jan. '56, p. 9), Chairman Strauss said in Albuquerque, N. M., that "there is relatively little about any area of the civilian applications of atomic energy which remains closed to any responsible American business man who has a need for such information. This policy represents what we presently believe to be the most judicious solution to the problem."

A-Ships Abroad Denmark's Burmeister & Wain shipyard, famous for huge marine Diesels, announced plans to enter the atomic power field; it has set aside $400,000 for research. In Tokyo it was announced preparation of blueprints for Japan's first atom-powered vessel would begin within six months.

Insurance Progress Three groups of insurance companies have formed pools to underwrite reactor hazards. Some 70 capital stock casualty companies set up a syndicate to provide $50-million coverage per accident for third-party liability; fire insurance companies pooled another $50-million to cover damage to the reactor operator's property; mutual companies are ready with another $10-million for either purpose. These sums, not dreamed possible a few months ago, made it seem increasingly unlikely Federal insurance legislation would be asked this year—or at all.

Fission & Fusion at MIT MIT has set up a thermonuclear study group led by Prof. William P. Allis, consultant to Project Sherwood at Los Alamos. Purpose is to see whether MIT should set up a program of experimentation in the fusion power field. MIT also disclosed that ACF Industries will design, and eventually build, the Cambridge school's research and training reactor. Similar to CP-5, the reactor will produce 1 Mw of heat; site, cost, flux level were not disclosed. It will be the first reactor in New England, and the first reactor job for ACF.

Spending Increases Planned for AEC Operations . . .

Program	1955 Actual	1956 Estimate	1957 Estimate
Source & special materials	$626,896,217	$878,524,000	$1,012,582,000
Weapons	238,184,541	267,139,000	282,470,000
Reactor development	109,155,473	159,927,000	234,935,000
Physical research	44,548,999	54,419,000	65,693,000
Biology & medicine	28,120,416	29,172,000	31,527,000
Community	18,977,296	20,065,000	17,950,000
Administration	33,953,408	38,016,000	38,327,000
Security investigations	9,817,431	6,807,000	6,610,000
Other costs	−10,360,343	5,270,000	6,375,000
Total costs	1,099,293,438	1,456,339,000	1,696,469,000
Revenues applied	−17,167,446	−30,226,000	−33,797,000
Net costs	$1,082,125,992	$1,426,113,000	$1,662,672,000

. . . as Commission Gets 16½% Boost in Budget for 1957; $237-Million Raise Includes $75-Million for Reactors

President Eisenhower has asked Congress to raise AEC's net operating budget for fiscal 1957 about 16.5% above the agency's rate of spending for 1956. The increase will provide:

- $1.4-million more in 1957 for the civilian power reactor program.
- $26.4-million more for the naval propulsion reactor program.
- $27-million more for the aircraft propulsion reactor program.
- $4.6-million more for training and education.
- $13.9-million more for other AEC programs.

Total spending for operations in 1957 is estimated at $1,662,672,000, compared with the fiscal 1956 estimate of $1,426,113,000. These overall gains in spending are reflected in the table above.

A large portion of AEC's 1957 money is to be charged off to research and development. For instance, in the $282-million listed in the above chart for weapons spending, more than $95-million will be r-&-d costs.

Even more important, from a financial standpoint, is the cost of r-&-d in the reactor program. More than $211-million of the reactor program's $235-million allotment is r-&-d. In 1956, the reactor program is estimated to cost $160-million; of this, $144-million is to be charged off to r-&-d.

Here's a thumb-nail rundown on the major AEC programs:

- Source and special nuclear materials—foreign and domestic procurement will continue to expand. AEC expects new facilities for processing feed and special nuclear materials to provide increased output at lower unit processing costs.
- Reactor development—stepped-up military and civilian reactor programs are in store. "Increasing emphasis" will be placed on a broad study of reactor control and safety. This endeavor will involve testing of basically different classes of reactors under adverse operating conditions to establish safe upper operating limits and to study the mechanisms which cause reactors to be inherently safe. Training in the nuclear engineering sciences will be expanded. This will include training in universities and Commission laboratories, plus provision of training equipment to universities.

AEC will add an eighth concept to the seven reactor approaches it is now supporting to develop commercially-feasible nuclear power. This is believed to be the gas-cycle approach (which AEC abandoned in 1947), although the Commission said it could not comment in advance of the Congressional appropriations hearings. AEC also will expand work on transportable reactors.

- Weapons—operation of expanded production plants will increase weapons output. Employment will increase.
- Physical research—AEC utilizes about 90 particle accelerators ranging in energy from a few hundred thousand electron volts to the 6-billion electron volt bevatron. A 25 to 35-Bev accelerator is under construction at Brookhaven. In 1957, increased effort will go into studies of improving high-energy accelerator design.
- Biology & medicine—radiation effects are chief objects of the program.
- Community—AEC still has the headache of operating Oak Ridge, Richland and Los Alamos.
- Program direction and administration—costs will represent 2.3% of total operating costs in 1957, compared with 2.6% in 1956. Employment will pick up.
- Security investigations — AEC and FBI full background checks are estimated at 27,150 for 1957, compared with 28,000 for 1956 and 44,918 for 1955.
- Other costs, revenues applied—AEC supplies materials and services to industry. Costs of these will total about $6.4-million in 1957, an amount to be deducted from income of $38-million received from their sale and income from community operations.

No new money was asked for new AEC plants. Obligational authority —permission to make contracts to spend money—was asked only for money already appropriated. There remains available a $79-million unobligated balance from previous years, and AEC feels this more than sufficient to cover $25-million for reactor development facilities and $2.5-million for its communities. The $25-million will go into construction of a prototype naval propulsion reactor and facilities associated with development of other

Reactor Program Costs

	1955 Actual	1956 Estimate	1957 Estimate
Civilian power program	$27,261,202	$36,794,000	$38,156,000
Army package power reactor	600,785	1,700,000	3,300,000
Naval propulsion	27,061,956	34,818,000	61,200,000
Aircraft propulsion	22,557,022	47,570,000	74,600,000
Training & education	771,072	937,000	5,583,000
Advanced development, operational services, and all other	30,903,436	38,108,000	52,096,000
Total reactor program	$109,155,473	$159,927,000	$234,935,000

military propulsion reactors.

The remaining $52-million of the unobligated carryover will be asked for later, when the agency submits to Congress a supplemental request for $196,081,000. Of this total, $81.1-million will be proposed for improvements and additions to existing production plants, which will increase their production and safety and decrease unit costs, raise weapons production, and provide more development facilities. Another item of $54.4-million will be proposed for facilities needed for the military propulsion reactor program, and $12.3-million will be requested for new research laboratory buildings and improvements and additions to existing research buildings and machines.

Washington Report

Military propulsion reactors assume new importance in President Eisenhower's program for 1957. The budget the President submitted to Congress last month provides a boost from $47.6-million in 1956 to more than $74.5-million in fiscal 1957 for the aircraft propulsion program, and it asks that 1956 expenditures of $34.8-million for naval propulsion be stepped up to over $61-million in 1957.

These funds are for reactor development. They do not include anticipated outlays for equipment and facilities with which to carry out this program. As a matter of fact, the President has in mind transferring almost $25-million in leftover 1956 funds to the 1957 budget to complete construction of a prototype naval propulsion reactor and facilities connected with development of other military nuclear propulsion units. His 1957 Navy spending program lists an $88-million item to finance construction of an atom-powered light cruiser of 11,000-tons displacement, as well as requests for procurement of six new atomic submarines and planning of a nuclear aircraft carrier. The President is asking $22.5-million for an atom-powered "peace ship" designed to tour the world on a good-will mission. The nuclear aircraft engine program is more research than developmental, at this stage. Word has leaked that equipment allied with a propulsion reactor has been hooked up to a stationary reactor and tested. But there have been no indications that the weight problems associated with shielding of an airborne nuclear power plant have been licked.

For ships, however, the story is different. Two atom-powered vessels have been launched. The Nautilus, the first submarine, has completed more than 25,000 miles without refueling, and the performance of its reactor has been far better than anticipated by cautious designers and engineers. The Seawolf, the second sub, has been launched, and delivery to the Navy is expected this spring.

Last year, the Administration felt that naval propulsion had advanced far enough to justify an attempt at building a large surface vessel powered by a reactor. Eisenhower made a bad choice when he linked this concept with the concept of an atomic peace ship, for his request touched off a debate in Congress which stalled the entire project.

This year, however, something should be done. The President's budget message showed no diehard insistence on a peace ship, but leaned instead toward models which, while military, would be working prototypes of commercial vessels. The light cruiser is the best example of this, for its 11,000-ton displacement is in the range of modern cargo vessel size; the Maritime Administration's famed Mariner, the fastest cargo vessel, displaces 10,000 tons.

More comparisons: A Mariner runs on 17,500 shaft horsepower, although its performance has never been announced. The Nautilus displaces about 3,000 tons. A Navy light cruiser of 11,000-ton displacement would seem to fit the bill as a model for a Mariner-type nuclear vessel from the standpoint of power. It also comes close to the type of tanker the administration has in mind. The reactor undoubtedly would be a PWR. The Nautilus has proved out this concept more than satisfactorily, and findings on performance of the liquid-sodium-cooled Seawolf will not be available for another year or so.

The Maritime Administration has asked American industry for proposals for a reactor-driven conventional steam turbine device, and for investigation of advanced propulsion design, probably a closed-cycle gas turbine engine utilizing reactor-heated gases. It is now carrying on an experimental program on a closed-cycle gas engine, and if a promising proposal to hook one up with a reactor comes along, the two studies would be joined.

Maritime has plans to ask a supplemental appropriation of about $16-million for production of a hull for a nuclear tanker. The agency is sold on the potentialities of such a ship, since its payload would be intact at the point of delivery, rather than depleted through consumption of some of the oil cargo. **There's a note of urgency** in Maritime's requests since officials realize they may be outstripped by Scandinavian competitors of American firms, if not by the Russians. But that same urgency is even more important in the Navy's program, for it is symbolic of the Nation's defense against an enemy.

For this reason, the Navy stands the best chance of obtaining Congressional approval of a ship designed as a warship, but with possibilities of conversion to a commercial vessel with subsequent modification.

Belgium Plans 3d Reactor; Will Have High Flux

Plans for a high-flux materials-testing reactor were announced by Belgium's Council for Industrial Applications of Nuclear Energy. It will be erected at Mol, on land adjacent to the first reactor—expected to go critical in April. The two will form a single industrial-scientific complex.

The proposed MTR will have a flux-rate of 6.45 x 10^{14} neutrons/cm^2/sec, which will make it the most advanced reactor on the continent. It is to be completed by the end of 1958.

This will be Belgium's third reactor. The second is the 11.5 Mw power reactor now being built by Westinghouse to provide electricity—and an additional spectacle—for the Brussels World's Fair of 1958; it is to be ready for operation in spring that year.

Belgium's Nuclear City at Mol stands in flat isolated country formerly part of the royal domain of Réthy, 29 miles east of Antwerp and only 7 south of the Dutch frontier. Aside from barge traffic on the old Scheldt-Meuse canal, its only neighbor is a power station from which the first reactor will buy electricity and hot water.

The first reactor, begun in July 1954, is almost completed. Like Britain's BEPO at Harwell, it is graphite-moderated and air cooled, in form a 20-ft cube surrounded by a 7-ft protective wall of dense concrete. Six cast-iron foundation plates each weighing 13,200 lbs have been laid perfectly level on concrete reaching 36 ft down into the sand. On them will rest 500 tons of graphite containing 25 tons of natural U in Al-clad slugs. The reactor will have a flux of 10^{12} neutrons/cm^2/sec, and will operate at 3 Mw of heat. Coolant air will be filtered and expelled through a 200-ft chimney. Though it will produce isotopes, principally short-lived ones, its essential function is experimental. Large chemistry, physics, biology, and metallurgy labs are now being built in the adjoining Mol pinewoods for completion by year's end; together with the first reactor, this center will employ 500, a quarter of them scientists. Like all other countries, Belgium is seriously worried about the shortage of adequately trained scientific personnel. Recently an appeal was made to writers to try to popularize nuclear physics as a career for young Belgians.

About the Industry

Road map for the chemical industry. Having been handed an AEC routing chart to the hitherto unexplored territory that is chemical reprocessing, the industry began girding for the long research and development trek. The directions were in the form of a new program "to encourage private industry to build and operate plants for the chemical reprocessing of irradiated fuel elements from research and power reactors, as a further step toward private ownership of atomic energy facilities for peaceful uses." AEC offered to make available to this end both its know-how and limited amounts of irradiated fuel from its reactors to those firms which submit acceptable proposals 18 months hence for construction of private processing plants. The firms may also use AEC facilities for research and development and for training, at their own cost. "The goal is to have commercial processing plants in operation as it becomes necessary to process fuel elements from privately-owned power reactors." In judging the proposals, AEC will consider the extent to which they advance the art, reasonableness of prices, size and start-up date, and the manner in which the waste disposal problem will be handled—the last inserted to give industry the greatest possible incentive to reduce the cost and risks of waste disposal and to develop economical uses for what are now considered waste products. As in the power demonstration reactor program, AEC may accept one proposal, several, or none.

Industry reaction was that this cleared the air, imparted direction that had been lacking. The program was announced sooner than some had expected, and the 18-month period was considered "an interesting time" reflecting the hope of seeing some advanced design thinking. It was none too soon, either: 18 months plus 2–3 years' construction time is just about right for carrying the load; some saw AEC forcing the pace. On the other hand there had reportedly been some jockeying for position earlier among chemical firms to line up utility commitments; the announcement evened them out and established a competitive bid situation—no utility now will not sit back and wait to see how much r-&-d can bring the price down. To qualify for AEC at the end of 18 months, however, a firm must have at least one private commitment. One criticism of the plan was that AEC failed to specify the base-load of government-owned fuel it would make available for processing; but the Commission assured NUCLEONICS that it intended to do so very shortly.

To explain its program and to define processing costs, AEC held a symposium at Idaho Falls. Some 200 chemical and utility people heard AEC Reactor Chief W. K. Davis read a basic statement spelling out Commission policy. AEC's target figure for processing is ½ to 1 mill/kwh, he said; this includes inventory during processing, processing losses, waste disposal conversion to metal and shipping costs of fuel elements as well as recovered products. AEC's own fuel processing costs are confidential data. Intent of the new aid plan "is to provide a base-load for economical operation of one or more commercial chemical processing plants until the load from private power reactors is sufficient to support the operation. If industry proposes to process licensed power reactor fuels only and does not require AEC fuels to supplement the load, they need not submit a contract proposal to AEC. They would still apply for a license to construct and operate the facility."

PWR's fuel-handling canal

Progress on PWR At Shippingport

(Right) A GENERAL view of progress on PWR as of Jan. 18. Behind the high-lift cranes can be seen the tops of the two heat-exchanger containment vessels

(Left) A CLOSE-UP of one of the two containment vessels for heat exchangers. Each will contain one Babcock & Wilcox U-shaped, and one Foster Wheeler straight-through heat exchanger

Reactor News

Details on new version of Yankee reactor disclosed. AEC's reactor chief W. Kenneth Davis recently revealed some of the specifications of the revised Yankee Atomic Electric Co. proposal, only one of the four original bids under the first round of AEC's Power Demonstration Reactor Program not yet accepted. The revised proposal, still under consideration by the AEC, calls for a plant generating capacity upped from 100 to 134 Mw, while total estimated plant cost rises only to $26-million from $20- to $25-million. Of this $19.3-million is for the pressurized water reactor, $6.7-million for the turbo-generator plant. Yankee's proposed $230-per-installed-kilowatt capital cost compares favorably with $630 estimated for the Shippingport PWR, $540 for Detroit Edison's fast breeder, $320 for the Nebraska sodium graphite reactor, $250 for Commonwealth Edison's Chicago boiling reactor; it matches the estimated $230 per-kilowatt capital cost of Con Ed's Indian Point thorium-breeding PWR, and is surpassed by none. It will have a thermal power of 500 Mw, and use 25,500 kilograms of 2.7% enriched uranium. (Enrichment compares with 90% for Shippingport and Indian Point, 20% for Detroit, 1.8% for Nebraska and 1.1% for Chicago.)

Los Alamos building 5 experimental power reactors. Norris Bradbury, director of Los Alamos Scientific Laboratory, revealed that LASL is engaged in "active research, design and construction" of five power reactor projects. At least two are quite daring in concept. As described by Dr. Bradbury, the five are:

Omega West—a forced-water cooled, heterogeneous reactor that will operate at about 5 Mw and will be completed in Spring. It uses enriched fuel elements of the type used in the Geneva swimming-pool reactor, and will be used as a research tool for neutron production and irradiation.

Los Alamos Power Reactor Experiment No. 1 (LAPRE 1)—a homogeneous, forced fuel circulation experimental power reactor now already in final assembly stage. It uses a solution of enriched uranium, phosphoric acid and water, requiring a gold lining inside the stainless steel core vessel to contain it. The reactor is cooled by forming steam in a heat exchanger. Core and heat exchanger will be enclosed in the gold-lined stainless steel vessel six feet high and 15 in. in diameter. Heat output will be 2 Mw. This is expected to be the first reactor to produce high temperature superheated steam as is used in modern turbines; but LAPRE 1 will have no turbine-generator attached; however the design can be scaled up substantially.

Los Alamos Power Reactor Experiment No. 2 (LAPRE 2)—another homogeneous reactor using enriched uranium, phosphoric acid and water solution for fuel. Convection cooled, it will be rated at 1 Mw. It has no moving parts and is designed for safe operation without an attending operator, making it especially suitable for "package power" applications. Construction is expected to be completed this year.

Push-Pull Critical Experiment—a small-scale test of a method of producing forced circulation of fuel solution without using pumps or other moving parts. It is comprised of two reactor vessels connected by a heat exchanger. The fuel solution fills and becomes critical in only one vessel at a time. When it goes critical, the rise in vapor pressure resulting from increased temperature in the chain-reacting solution forces the fuel solution through the heat exchanger into the other vessel, halting the chain reaction in the first vessel but going critical in the second. When the second vessel is full, the process is repeated in the reverse direction. It is expected to be completed in six months.

Los Alamos Molten Plutonium Reactor Experiment (LAMPRE)—A molten-plutonium-alloy-fueled reactor that will operate at high temperatures, this system can be made a breeder. Pilot model will develop ~1 Mw of heat, but a 100-Mw unit is being designed.

World News

French dual-purpose reactor started up. France became the second country in the world, after Russia, to have an operating nuclear central station plant on Jan. 7, when her "G-1" reactor went into service at Marcoule near Avignon in the lower Rhone valley. Air-cooled like the Brookhaven reactor, G-1 is fueled by 100 tons of natural U shaped in 2,700 rods, and moderated by 1,200 tons of graphite. It will produce 33 pounds of plutonium a year. Conceived as a prototype, it will have a heat capacity of 40 Mw; a generating station, now nearing completion and planned for service in July, will produce 5 Mw of electricity. This low power output is due to the relatively low heat produced: 280° C.; and it will not be available for consumption as G-1's air blowers will require 8 Mw. However G-2, a larger CO_2-cooled sister reactor to be completed next year, will produce 50 Mw of electricity so that the two reactors together will have a net surplus of 15 Mw for sale.

Russian reactor aid for Tito. A Yugoslav delegation to Moscow returned to Belgrade with an agreement under which the Soviet will provide technical aid in building Yugoslavia's first research reactor, as well as supplying nuclear materials. The agreement also calls for exchange of scientists and professional literature. Yugoslav officials said they hoped to complete the reactor in 2–3 years. They would not disclose its size, said only that it would be larger than those Russia is supplying to its satellites, but smaller than the 5-Mw Soviet power reactor. They said Russia's offer of aid came in response to a Yugoslav request that went also to the U. S. but was answered first by the U.S.S.R.

Austria sees delays. Delegates of the Austrian AEC are reported in Vienna newspapers as encountering difficulties in obtaining usable data on commercial atomic reactors from U. S. manufacturers. The team of experts had been sent here to get sufficient data on reactor types to be able to select the best model for research-and-power. Viennese officials had also invited a team of U. S. specialists to visit Austria to study prevailing conditions, but no American scientist or industrialist had shown up by year's end, the Austrian commission said. Meanwhile the bilateral with Austria cannot be signed because the U. S. AEC wants to know first what kind of reactor Austria wants to buy.

Germans sell reactor components to Commonwealth. Head Wrightson & Co., the Yorkshire firm building the Australian power reactor at Lucas Height near Sydney, has sub-let part of the work because its own works were at full capacity. The Bavarian heavy engineering firm M.A.N. (Maschinenfabrik Augsburg Nürnberg) received an order for heat exchangers and other components.

Living with a reactor: English townsfolk differ. Although Essex County Council approved in principle the selection of Bradwell-on-Sea in Essex as one of the first two British nuclear power station sites (NU, Dec. '55, p. 14), residents of the town of 800 are up in arms. Objections are to industrialization generally. An alderman asks, "Why should we have one here? We do not care to have experiments tried on us." Loudest protests are from Essex Bird Watching and Preservation Society; the site is close to a suggested nature reserve. Contrariwise, the people of Berkeley in Gloucestershire, the other site chosen, are "all rather thrilled about it," and look forward to "being on the map again."

Cheap isotope separation in Germany? Scientists at the University of Marburg claim to have discovered a relatively cheap way of separating uranium isotopes. Production of U-235 is the bugbear of European atomic development today, just as it was earlier in the U. S.; and the American example of about $3-billion spent on diffusion plants—using half as much electricity as Germany's total annual consumption—is not encouraging. A cheap separation process would have political significance, too, because the vast cost of diffusion plants is a prime argument in favor of a "Euratom" pool plan. The Marburg scientists force UF_6 gas under high pressure at ultrasonic speed through flat nozzles about 0.02 in. wide. The lighter parts of the gas tend to accumulate near the fringes of the gas stream and the heavier ones near the center. Experiments to date have been made using xenon; 12 nozzles arranged in a circle, each one a yard long, have been used, with the heavier gas being separated by a diaphragm. German industrialists think building and operating costs of separation plants may be cut by one-half to two-thirds.

India expands rare earth facilities. The Government's $2-million rare earths factory at Alwaye (Travancore-Cochin) will increase its production "substantially," Dr. Homi J. Bhabha of India's AEC said. Present output of the 3-year old plant, said to be unique in Asia, is a secret. It processes monazite and produces thorium, rare earth carbonates and trisodium phosphate. Dr. Bhabha also reported discovery of three uranium deposits in India; and that Vitro Engineering, together with France's St. Gobain and Britain's Costain John Brown, had been named technical consultants to the Indian government to prepare preliminary reports for the D_2O plant and fertilizer factory to be set up in conjunction with the Bhakra-Nangal dam now being built. The plant is to make 7½ tons of D_2O annually as well as 340,000 tons of ammonium nitrate fertilizer. Last week, Dr. Bhabha and India's electricity supply chief agreed on the site of India's first power reactor: at the textile center of Ahmedabad. This city's distance from the main Indian coalfields makes A-power more urgent here than in Bombay or any other industrial city.

High Energy Physics Symposium at Geneva. CERN, the European Organization for Nuclear Research, will hold a symposium June 11–23 on "Novel features in the design and techniques of high energy accelerators." Special experimental techniques such as bubble chambers and new contributions to pi meson physics will also be discussed. Participants will be held to 300.

Study Group for Nuclear Energy founded in Vienna. Individuals and companies have been invited to join the "Studiengesellschaft für Atomenergie" by buying from 1 to 5 shares at 30,000 schillings ($1,154) per share. More than 65 shares have been sold; 30 of 80 firms invited have joined. The group's future activities were not announced.

Italian nuclear power prospects. Italy needs 1-million kw of nuclear power by 1965 and several millions by 1975; and in all probability nuclear power will be competitive in Italy by 1960–63. So says Vittorio De Blasi, managing director of Societa Edison of Milan, Italy's biggest electric power utility. He urged Italian industrialists to plan to get in a position to be able to build all or part of these plants, because of Italy's unfavorable balance-of-trade situation. It is not yet clear whether, or to what extent, Rome will control Italian private industry's atomic activities.

ROUNDUP

News in Brief

Industrial radiation conference set. Together with the Armour Research Foundation, NUCLEONICS will co-sponsor an Industrial Nuclear Technology Conference in Chicago on May 15, 16. It will cover uses of radioactive materials in many industries and in chemistry and biology, as well as radiation sources and nuclear instrumentation.

Gas-cycle proposal for PDRP. Holyoke, Mass., one of the first to disclose interest in the second round of AEC's power demonstration reactor program, (NU, Dec. '55, p. 14) announced a definite bid. Its revolutionary proposal is for the world's first closed cycle gas-cooled reactor. This 15 Mw plant would have a single loop in which reactor-heated nitrogen under pressure would be channeled into the turbine, back to the reactor; no steam cycle, no heat exchanger. Ford Instrument Co. would design and build the reactor; Sanderson & Porter, consulting engineers, would design the plant and supervise construction. Capital cost would be $310 per installed kw, although r-&-d work brings total cost to $10-million. Meanwhile another city utility, at Piqua, Ohio, is pushing plans to bid.

Army transport study contract to NDA. Nuclear Development Corp. of America won a $100,000 contract to study for the Army Transportation Corps the feasibility of nuclear propulsion for military transport including locomotives, harbor and inland waterways craft, and large cargo-carrying "land trains."

No LMFR for Pacific Northwest yet. The Washington State Power Commission has decided to delay entering a bid under the second round of PDRP for a small liquid metal fueled reactor (NU, Jan. '56, p. 16) after comparing prospects with a conventional plant using coal.

AEC prices thorium. A "revised" basic price of $43 per kg, F.O.B. Fernald, Ohio, has been set on thorium by AEC. Use of the word "revised" referred to an earlier confidential price; this is the first publicly announced price. The revision appears to have been upward; AEC would not confirm this but said the new price is in line with its policy of full cost recovery. AEC said it plans to "sell or lease thorium metal in limited quantities only until industry is prepared to meet commercial requirements." Reactor chief W. K. Davis recently said AEC was stockpiling Th in a limited way.

New home for AI. Atomics International division of North American Aviation has moved its headquarters across Los Angeles from Downey to a new 85,000-ft² building at Canoga Park. Both administrative and laboratory work will be carried on in the new building, only 8 miles from Santa Susana where the Sodium Reactor Experiment is going up and where AI has a laboratory for heavy nuclear research and development work.

New contract for Mallinckrodt. AEC has signed a new contract with Mallinckrodt Chemical Works of St. Louis, operator of AEC feed materials plants in that city and at Weldon Springs, 27 miles west. The new four-year contract, reflecting the increased scope of Mallinckrodt's work for AEC, switches to a cost-plus-fixed-fee basis; the previous pact provided for production at a unit price, and for r-&-d and minor construction on a cost-reimbursement basis.

Feed materials meeting well attended. 54 industrial firms were represented at an AEC-sponsored technical information meeting in Cincinnati last month in connection with the Commission's proposal for production of refined uranium salts in privately-owned and operated plants. (NU, Dec. '55 p. 13.) 140 L-cleared persons heard technical papers and were taken on a limited tour of the Fernald Feed Materials Center.

Another AEC bid to private industry. AEC asked industry bids for processing of fluoride scrap generated at feed materials plants, to recover U contained in it. It is expected sizable quantities of commercial fluorine could also be recovered. AEC estimates 4,000 to 8,000 tons of fluoride scrap will be available annually; it is now being stored. The Commission will give industry until October to familiarize itself with the processing technology involved, and then will invite bids for purchase of scrap and re-sale of recovered uranium.

Plane-installed reactor flies. The Air Force and Convair announced that a test reactor has been installed in a B-36 for investigation of shielding effects of radiation on aircraft materials and systems, and to develop airborne nuclear instrumentation. The reactor operates only while the plane flies over designated areas where maximum public safety is attainable, never during take-offs or landings.

New industry building plans. Nuclear Development Corp. of America began work at Pawling, N. Y., on a reactor critical facility developed entirely with private industrial funds. The $500,000 nuclear experimental station will also have a hot lab; both facilities are to be in operation by midsummer. High Voltage Engineering Co. announced an 88,000-ft² building at Burlington, Mass., near Boston, to house the world's largest radiation machine test facility. Edward Valves, Inc., builder of valves for both Nautilus and Seawolf, is doubling the size of its Chicago lab where it develops, tests, and assembles valves for nuclear power plants.

Detroit site set. Lagoona Beach, 30 miles SW of Detroit on Lake Erie, is the site of Detroit's fast breeder. Its builders—18 utilities and 8 manufacturers—have formed Power Reactor Development Co. This "construction group" is distinct from the r-&-d Atomic Power Development Associates; both are spearheaded by Detroit Edison.

Enter the Atomic Coordinator. Henry M. Marx of Greenwich, Conn., special counsel for General Dynamics, has been named Atomic Energy Coordinator for Connecticut by Gov. Ribicoff. He will protect the interests of the public, promote the use of atomic energy, and coordinate the activities of nine State agencies.

Regulations out. The first 6 regulations under the 1954 act, published in tentative form last summer, went into effect. Modifications in the tentative version were minor, mostly liberalizing. Three more will be out soon.

AEC isotopes reorganization. The Isotopes Division at Oak Ridge, at present the only AEC division with headquarters outside Washington, has become the Isotopes Extension of the Division of Civilian Application. Closer coordination is the aim of the change.

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Two lead brick size 2" x 4" x 8" – one cast in an open mold (right), the other extruded through a die in a hydraulic press (left)—were sawed in half lengthwise, to show internal structure. After planing and buffing, the halves were photographed. The photos were retouched to kill highlights and achieve uniform tone on both brick. The sink and shrink-hole were not touched.

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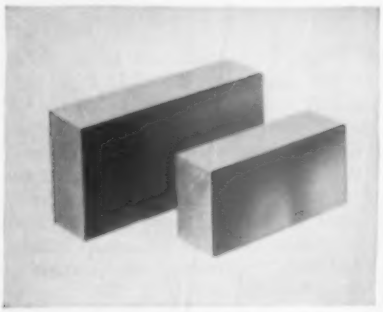

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The quantization performed by Ford is not restricted to color alone. For example, a black and white photograph represents an aggregate of light and dark areas of varying shades, and this display must frequently be converted into continuous or discrete electrical quantities for various purposes and uses. Ford engineers recently developed equipment which can quantize and record the various degrees of color, or gray areas in photographic negatives, and to correlate this information into usable data. This equipment was developed for a classified project – the equipment is unavailable for general use – however the technical know-how gained by Ford – combined with Ford's superior production and engineering facilities – is available in the creation of light quantizing equipment for you.

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CRISIS: Nuclear Education

[Editor's Note—*With the blossoming of the nuclear industry, the manpower shortage has become a serious problem. It has been said that production of new nuclear engineers and scientists must be tripled if we are to keep up with growth curves. Training opportunities are increasing, but not fast enough. Here is an analysis of the situation by John Kenton, News Editor of* NUCLEONICS.]

The biggest crisis facing the United States atomic energy industry is that of training scientists, engineers and technicians in adequate numbers.

Yet it is only quite recently that the seriousness of the situation has been recognized and grasped. When Commissioner Willard F. Libby sounded the alarm last May, at the dedication of the first university research reactor at North Carolina State College, his was a voice in the wilderness. Since then the tocsin has been rung; today there is probably no one connected with the field who has not heard government or industry leaders point out that

- we are training half as many new engineers each year as we must have;
- Russia is currently training more than twice as many new engineers each year as we are, and is substantially increasing her output;
- only 16% of high school graduates entering college enroll in engineering courses; less than 8% graduate as engineers;
- the number of qualified high-school science and mathematics teachers has fallen off 53% in the last five years—while the student body went up 15%;
- 53% of our high schools do not teach physics at all. . . .

But although in the last quarter of 1955 both government and industry, as well as the universities, began to take remedial measures in the nuclear engineering field, these so far amount only to a finger thrust into a man-sized hole in the dike.

One obvious reason why the crisis in nuclear education matured and broke so suddenly upon the infant atomic energy industry is that hard on the heels of passage of the Atomic Energy Act of 1954 private companies began swarming into the new field, and the demand for trained personnel skyrocketed. Companies intensified their bidding for the services of experienced AEC people, and then turned in some cases to cannibalizing each other's staffs.

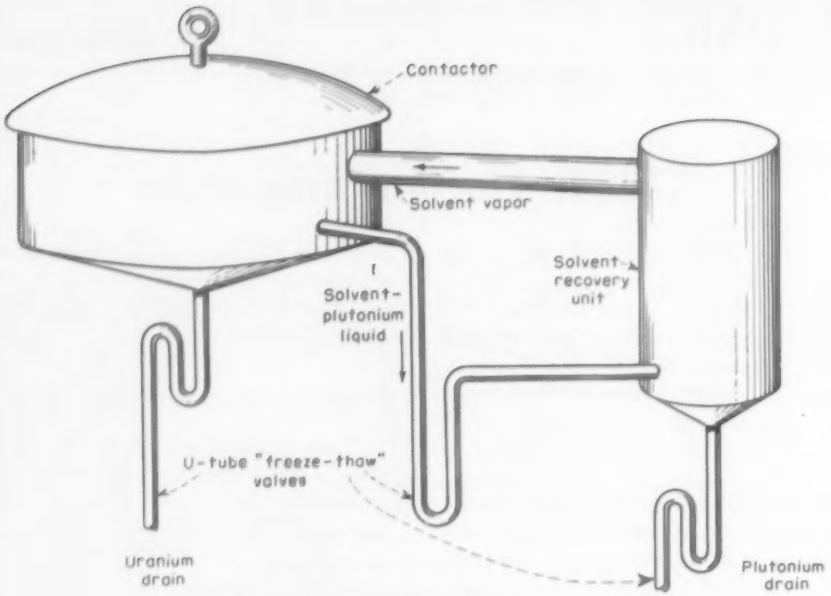
The Scope of the Problem

There are today 14,000 engineers and scientists in the entire AEC program, and 4,000 more in industry and the universities. This includes the specialists in mining, agriculture, biology, and medicine, weapons programs—everything. Of nuclear engineers there are only 5,000 in the country altogether, in and out of AEC. And even at that, only a few of this 5,000 are highly qualified men with five years' or more experience who have either worked through reactor design projects from beginning to end, or become expert in nuclear chemistry or metallurgy or radiological safety. The rest are trained men who have gone into ancillary fields such as economics, technical or contractual services, labor relations, government liaison or regulation; or who are trained in and have worked on only one limited specialty such as reactor physics, or heat transfer; or who have completed training but have as yet little or no practical project experience.

AEC estimates that the civilian atomic energy industry will need 2,000 well-trained nuclear engineers and scientists each year for the next three years, and that at present we are training about 500 per year. Moreover, conservative growth curves indicate a need for 40 to 50,000 engineers and scientists in atomic energy work alone by 1975, to achieve which the training rate must be lifted by then to 5,000 a year. But U. S. Office of Education studies show that by then we will be training only about 35,000 engineers annually in all fields, so that atomic energy could utilize 15% of the total available supply of engineers. Obviously competition for them will be such that 15% will not be available; the 18,000 nuclear scientists and engineers today represent 2% of the 850,000 total.

This is why AEC is concerned about the long-range as well as the immediate problem, and why it has expressed fear that manpower may become a limiting force on the rate of expansion of

Continued on page 52



PROPOSED system for extracting Pu from irradiated fuel

Pyroprocessing for Nuclear Fuels

Advantages of pyroprocessing over conventional aqueous processes are:

1. Inorganic and metallic materials are compact and radiation resistant

2. Thus, plants should be smaller and not restricted in location by fluid radioactive wastes

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Current Practice—Aqueous Processing

Aqueous systems are used in government plants for isolating decontaminated plutonium and uranium from irradiated uranium. The process involves dissolution in nitric acid and preferential extraction of the plutonium and uranium into organic solvents, such as methyl isobutyl ketone or tri-n-butyl phosphate diluted with a hydrocarbon (13).

Presumably this technique is applicable to any irradiated uranium, although there is no plutonium separation step with irradiated uranium-235, as in the Idaho Chemical Processing Plant (nor would there be with uranium-233) (14). *A parallel process has been developed to separate uranium-233, protoactinium-233, and thorium from irradiated thorium* (13). *Precipitation processes using $BiPO_4$ and LaF_3 as carriers have also been used for plutonium recovery* (1).

Such aqueous processes give the extremely complete decontaminations (separation factors for radioactive nuclides of 10^7 have been mentioned) necessary for the direct handling of recovered products without shielding, as is necessary in manual fuel-element manufacture (1).

Several requirements, namely, (1) shielded remote operations, (2) virtually maintenance-free design, (3) avoidance of critical mass accumulation, (4) complete decontamination, (5) freedom from escape of radioactive nuclides, and (6) high recoveries set by the values of materials, result in processing facilities and operating costs that are much more expensive than conventional industrial chemical operations. For example, a capital cost of $6,000,000 has been estimated for a plant treating only a half ton of irradiated natural or slightly enriched uranium daily (15).

Improvements in aqueous methods are to be expected. However, cost reductions may be limited by low solubilities in water and organic solvents since this, in a general way, indirectly determines the physical size of the plant. In addition, there are indications that intense radiation decomposes some processing agents; for example, water decomposes to hydrogen and oxygen creating an explosive hazard (16). *This means that radiation damage might prevent, or at least complicate, the application of aqueous techniques to freshly irradiated materials.*

THE REQUIREMENTS of reactor fuel recovery may make unusual demands on existing processing methods (see section on "Aqueous Processing"). Certain nonaqueous processes have been proposed as alternate separation techniques (*1*). One general type is high-temperature processing (pyroprocessing), such as molten-metal or fused-salt extraction and slagging, analogous to methods used successfully in the metallurgical industries.

The following discussion presents some of the engineering problems envisioned for pyroprocessing. An example of such a separation system is described.

Although processing used fuel and fertile material is normally considered a necessary part of the nuclear reactor complex, it can only be justified for commercial reactors if processing costs are less than the value of the recovered nuclides. Currently, the concensus is that the value of plutonium, uranium-233, -235, and -238, and thorium will be high enough to permit their recovery. Some feel that ultimately fission products will have significant value and will have to be taken into greater account in determining processing methods.

Fuel and fertile material from mining and refining uranium and thorium ores, which is the alternate source to reactor processing, will influence the processing picture, but the effect is difficult to evaluate. Whether or not there is processing to recover valuable nuclides, some sort of treatment may be justified to reduce charges for disposal of radioactive wastes.

Processing load for a given reactor power level can vary widely and is related to the irradiation time. This may be determined by a number of considerations, such as: (1) loss in reactivity from fission-product accumulation and fuel depletion; (2) mechanical failure of the fuel or fertile system, examples being distortion of fuel units, corrosion of cladding, and undesirable precipitations from fluid systems; (3) optimum production of a nuclide, possibly plutonium or uranium-233, since limited irradiation prevents excessive loss of the product by either neutron capture or radioactive decay.

The processing load may be very low, as with the high-burn-up natural or slightly enriched uranium reactors, which might consume 1% of the total uranium before processing (equivalent to about 10,000 megawatt days of irradiation per ton of fuel) (*2*). As an example, if the power-reactor design studied by the Pacific Gas and Electric and Bechtel Corp. industrial power group (500 Mw, heavy-water moderated, light-water cooled, 60 tons of natural uranium) were operated at this burn-up, the irradiation time would be roughly 1,200 days. Thus, the entire batch of fuel would require processing only every three to four years (*3*). Obviously, a small processing load can lead to processing costs being a relatively insignificant part of the total costs of the reactor complex, even though the processing cost per unit weight is large. However, it must be realized that reduction of processing costs in this manner may also entail added costs for other operations, e.g.,

long-lasting fuel units may be more expensive.

At the other extreme, there will be a large processing load whenever the irradiation time is short. This situation could arise with some proposed fluid reactors, such as the Brookhaven liquid-metal-fuel reactor concept with its continuous integral processing system (*4*). Also, a relatively higher processing load may result with reactors designed to have a blanket of fertile material from which fissionable material is separated and sent to the core. In addition, a high processing load is necessary to utilize radiation from short-lived fission products (*5*).

General Considerations

Attractive aspects of pyroprocesses are:

1. Materials are handled in metallic form, leading to small volumes and fewer chemical conversion steps in returning products to a useful form, which is often metallic.
2. Processing agents are elements or inorganic compounds that are relatively resistant to radiation damage.
3. Radioactive wastes are recovered in a more compact form for use or storage.

Thus, pyroprocessing might be the ultimate in compactness and be the only practical way to handle freshly irradiated materials.

An unattractive feature is the practical difficulty in approaching the high decontamination obtained by aqueous schemes. If high decontamination is not attained, remote operations with the products may be feasible or aqueous techniques could be called on for assistance. Also, there may be difficult engineering problems in adapting the batch techniques of conventional metallurgy, e.g., melting and transfer of molten materials, to radioactive operations.

Plant location. Location of pyroprocessing plants should be less restricted than for other types because of the relative absence of fluid radioactive wastes. Since the optimum size of such plants should be smaller than for aqueous plants, perhaps individual reactors can have their own processing facility with the accompanying advantages of flexibility and independence from the operations of others. Such individual processing plants might be an integral part of the reactor building so as to share facilities and hence costs.

Plant facilities. Equipment and over-all plant size should be relatively small. For example, the average load from the 1%-burn-up reactor would be about 100 lb of uranium metal a day, which is the order of only a gallon. Even if the burn-up were only a fraction of this, processing volumes would still be a matter of gallons a day rather than thousands of gallons a day as might be expected with dilute aqueous solutions. Based on this, process containers are estimated to be at most a foot or two in diameter and a few feet high for a sizeable capacity. For such equipment, a shielded cell 20 or 30 ft across and 10–15 ft high should provide adequate space.

Shielding. Plant layout might be a shielded cell of circular or polygonal cross section with a central shaft rotated from the outside through a gas seal. The shaft would carry a rotatable radial arm, supported by a wall rail and holding manipulators with radial and vertical motions. A thin stainless steel welded cell lining, possibly type 347 to simplify welding, should be provided to minimize contamination and to simplify decontamination. The problems do not appear far different from those posed by aqueous plant equipment.

Shielding with ordinary concrete would probably be best, although higher-density concretes may have advantages in special arrangements (*10*). As a conservative estimate, the radiation energy in the average daily fuel load from the first-mentioned reactor (100 lb) would amount to about 25 kw (*11*). Assuming an average gamma energy of 2 Mev and a point source, about 10-ft-thick cell walls of ordinary concrete would be required (*12*) to reduce the radiation to tolerance.

Maintenance. Remote maintenance seems necessary. New equipment, not very large in this case, is installed remotely and contaminated equipment removed remotely to a separate shielded area for decontamination. The remote equipment would also be used to charge and discharge feed, products, and processing materials. Direct maintenance, whereby installed equipment and its surroundings are decontaminated prior to manual maintenance, appears very difficult with this type of process.

Plant power. Power would be electrical. Electric motors would provide mechanical movement in the cell, although hydraulic devices or shafts with seals to the outside are alternates.

Electric heating could be either by induction or resistance. Movable induction coils would give flexibility, allowing one to heat different parts of the same containers or other containers with a minimum number of coils. Induction heating requires nonsuscepting supports or cooled ones. An estimate of 1 kw of high-frequency power to melt a pound of metal in an hour would mean a motor-generator set of a few hundred kw (*14*). This means a large heat release in the cell, and cooling must be provided. Coolant in any heat exchanger, induction coils, or the fluid in any hydraulic system should be nonreactive with the processing materials; hydrocarbons, e.g., kerosene or Dow-Therm, are possibilities. Resistance heating might employ molybdenum resistors. The self-heating of freshly discharged fuel from fission-product radiation might be sufficient to cause melting and would have to be considered in design.

Inert atmosphere. A nonreactive atmosphere, vacuum or inert gas, is necessary with the molten metals and vapors to be handled. A vacuum seems a little more difficult to attain and maintain than a helium atmosphere. Entrance channels or tunnels would need appropriate gas locks to permit change of atmosphere from air to helium. Some sort of gas-cleaning system must be provided to treat the small excess developing in the cell. Scrubbers and low-temperature charcoal absorbers should be suitable.

Analytical control. New methods of sampling and analysis for use in the cell are required. A possibility is a neutron-multiplying device in which a container with fissionable material, possibly with some moderator, and an appropriately located neutron source would result in a neutron multiplication of an amount related to the fissionable material content. Such an analysis for fissionable material, or reactivity, might be of more interest to the reactor operator than absolute isotopic analysis. Experience with critical assemblies and exponential experiments indicate that such an analytical device is feasible.

Suggested Processing System

As an example of the equipment necessary for high-temperature separa-

tions, a device is proposed (see illustration) for extracting plutonium from irradiated natural or slightly enriched uranium with molten silver. This choice of solvent is based on the report that several molten metals, e.g., cerium and silver, act as plutonium solvents in such systems (*15*).

In the suggested system, the fuel is melted in the contactor; silver is added to extract the plutonium. The silver then flows to the solvent recovery unit where it is vaporized away from the Pu and condensed in the contactor for reuse. The Pu is discharged to a shipping container. The treated uranium (raffinate), discharged from the contactor, may be freed of solvent by vaporization if solubility is appreciable and boiling points are favorable.

"Freeze-thaw" valves regulate the fluid flow. Graphite U-tubes surrounded by a liquid-cooled, high-frequency induction coil might be used. Current through the coil would heat the graphite, melt any contained material, and open the valve. Control of the amount of heating and cooling should give partially opened positions and, thus, flow-rate control. Experimental work on the fluidity of metals indicates the feasibility of such valves (*16*). Heated U-tubes with the appropriate liquid legs would give vapor seals as desired.

Mechanical movement of materials is limited to the transfer of solids (feed, products, and make-up solvent). Movement of liquids in process is by gravity with "vapor pumping" providing the necessary head. In this manner, certain mechanical equipment, for example, that for lifting and pouring fluxed materials, is replaced by heat input, thus simplifying engineering.

The contactor described in this batch operation is simply a pot container acting as a single stage with agitation from induction currents, density differences, or stirring. More efficient continuous extraction would require more complicated equipment. Possibly a multistage mixer-settler or a column contactor analogous to that used in aqueous solvent-extraction schemes, but fabricated of the appropriate refractory material and heated, might do multistage extractions continuously. Molten uranium could be introduced continuously to such equipment.

Conventional unit operations used. The unit operations employed and their combination are exactly those widely used in conventional chemical engineering at ordinary temperatures with materials like water and organic solvents. "Freeze-thaw" valves, "vapor-pumping," and refractory materials of construction permit these operations at very high temperature.

Application of this device depends on the availability of a solvent that is immiscible with the material treated and that has a boiling point above the melting point of the material treated but well below the boiling point of the extractable component. Pressurizing would remove the first boiling point restriction, but this is not attractive in view of the problem with construction materials. The solvent can be lighter or heavier than the feed treated. However, the description given here is for a lighter solvent, as few materials exceed the specific gravity of uranium (over 18). If the extractant were a fused salt, e.g., an alkaline earth halide, and the plutonium were extracted as a halide, then it might be possible to add sufficient molten alkaline earth metal to the separated salt phase in the solvent recovery unit to reduce the plutonium to metal.

Construction materials. Choosing satisfactory construction materials to withstand the high temperature and the resulting corrosion and thermally induced stresses appears most difficult. Operating temperatures would be between the melting point of the feed and solvent and the boiling point of the solvent. The melting points of silver, uranium, plutonium, and thorium are 960, 1,133, 632, and 1,690° C; the boiling points are 2,212, 3,900, 3,235, and over 3,000° C, respectively (*17*). Some reactor fuel systems have quite different melting points, possibly much lower.

Graphite is one of the best high-temperature materials, and is also a susceptor for induction heating, but carbide formation may prevent its application. The high-melting metals, Mo, Cb, Ta, etc., are possibilities as are the high-melting oxides MgO, BeO, ZrO_2. The nonmetallics are probably more subject to failure from mechanical and thermal stresses. Lowering the boiling point of the solvent by reducing the pressure would give more latitude in choosing materials of construction—with added vacuum-equipment cost.

Conclusions

No fundamental obstacles appear to prohibit the application of pyroprocessing. However, considerable development is required. Whether any pyroprocesses can compete with the aqueous processes backed by experience will probably be determined only by pilot- or operating-scale studies.

The primary aims of the reactor complexes that have operated have been either plutonium production, military power (for example, submarine), or research and development. Current aqueous processes have had to be tailored to these aims and underwritten by the weapon value of fissionable material. Truly commercial nuclear-reactor complexes supported by the sale of power—and any value that can be derived from radiation—may require either variations of processes in which the government has large investments or new processes.

* * *

The authors wish to acknowledge material developed for Project Separation, which served as a basis for this discussion.

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Calibrating a Neutron Facility for Biological Research

This convenient facility provides 9.0 × 10^5 thermal or 2.3 × 10^5 fast neutrons/cm^2/sec with low gamma-ray contamination. Calibration techniques include a new graphite ionization chamber for gammas and Hurst's multifoil technique for neutrons

By H. J. CURTIS, S. R. PERSON, F. B. OLESON, J. E. HENKEL, and N. DELHIAS
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BOTH FAST AND SLOW neutrons produced marked biological effects (*1–6*). The basic mechanism by which these effects are produced is largely unknown.

To study these phenomena it is necessary to have a high-intensity source of both fast and slow neutrons uncontaminated with other radiations. Such a facility has been developed at Brookhaven. Its design, construction, and calibration are discussed here.

Flux Calibrations

Here's how the several radiations present in the biological facility are measured.

Thermal-neutrons. The neutron flux is estimated by the radioactivity induced in a 1-cm^2 weighed disk of gold foil exposed along with the material. The induced activity is measured on either an end-window G-M tube or a scintillation counter.

The counters are standardized by the coincidence-counting method (*7*). The activity of gold foils decays quite rapidly; therefore, at the time of standardization the response of the counters to the essentially unchanging activity of a uranium source is measured. This source serves as a continuing check on the constancy of the counters.

From the exposure time of the foils accompanying the experimental material, the estimates of their absolute activity, and the known neutron cross section of gold, the neutron flux is calculated. It is felt that these values are accurate to within ±5%. At a 26-Mw power level the flux at the bottom of the empty Lucite exposure box is 9.6 × 10^5 n/cm^2/sec. Since the flux is affected by reactor power, control-rod pattern and reactor poisons, as well as local neutron absorbers the flux should be measured with each exposure.

The foil measurements give the total dose delivered to the material, but it is necessary in many cases to deliver a predetermined dose to the material. It has been found that the leakage flux of neutrons coming through a hole in the top of the elevator shaft is proportional to the flux inside the exposure cavity. This proportionality has been determined, and a BF_3 counter monitors the leakage neutrons, from which an estimate can be made of the dose delivered to the material at the time of delivery. The proportionality factor depends on a number of factors that are difficult to estimate, and so doses estimated from the leakage neutrons are not as accurate as those estimated from the foils, but they serve a very useful purpose.

The flux is essentially uniform across any horizontal plane in the exposure cavity, but varies in a vertical direction. In one representative run, the flux varied in an exposure box from 9.6 × 10^5 n/cm^2/sec at the bottom to 7.5 × 10^5 n/cm^2/sec on the top shelf 6 in. up. The presence of neutron-absorbing material (biological material is only mildly absorbing) will of course change the neutron flux, so for accurate work it is necessary to put a foil in with each sample.

Fast neutrons. Fast contamination in the thermal column is estimated from the cadmium ratio, the ratio between the flux as measured by a bare gold foil and one covered by a sheet of cadmium. The cadmium ratio has been found to be about 4,000 at all times, and thus it seems reasonable to say that the thermal-neutron facility is uncontaminated with epithermal or fast neutrons.

Gamma-ray contamination in thermal column. The gamma-ray leakage from the Brookhaven reactor core has been found to be about 5,000 rep/hr. Eight inches of bismuth will reduce these gamma rays by about a factor of 1,000, which means that the gamma-ray contamination in the exposure cavity from this source can be neglected.

In addition there are gamma rays from neutron capture in the thermal column. Measurement of this component is difficult because of the high neutron flux also present. Several methods have been used to measure this contamination.

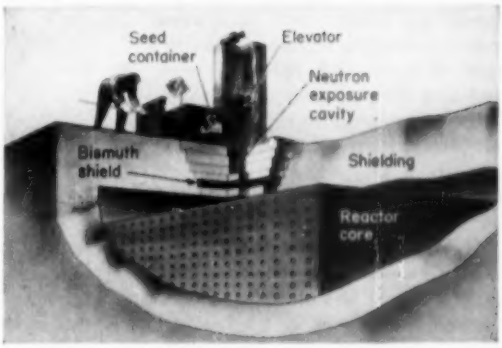
The first method is essentially the one employed by Darden and Sheppard (*8*). A box is made of boron-carbide-impregnated Lucite with walls thick

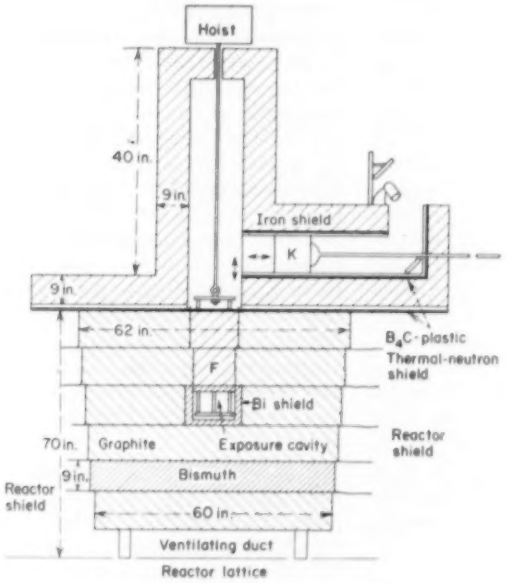
* Research under the auspices of the U. S. Atomic Energy Commission.

The Brookhaven Neutron Facility

A ~5-ft-square section was removed from the top shield of the Brookhaven reactor and the thermal column substituted for it. The 9-in. layer of bismuth at the bottom absorbs almost all of the gamma rays from the reactor while letting through the fast and slow neutrons. The 1-in.-thick bismuth box surrounding the actual exposure cavity absorbs some, but not all, of the gamma rays generated by neutron-capture reactions in the graphite.

The section of graphite immediately over the exposure cavity can be lifted by a power hoist into the shielded shaft above the column. The top of the bismuth box is fastened to the bottom of this graphite section and a graphite platform is supported below this bismuth by means of magnesium rods. Material to be irradiated is placed in a thin plastic box ~8-in. cube. It is then lowered into the tunnel and pushed along the tunnel on brass guides until it is on the graphite platform, which has been brought up to the level of these guides. The hoist then lowers the section in place. The process is reversed to remove material, a vacuum hook being used to pull the container box out of the tunnel. Limit switches on the hoist mechanism automatically stop the graphite plug and platform at the correct positions either up or down. Material can be inserted or removed routinely in less than 10 seconds.





A sheet of cadmium immediately over the thermal column and lining the elevator shaft eliminates neutron leakage. The 9-in. steel plates reduce gamma-ray levels outside the facility to well below tolerance. It is possible for an operator to work at the facility continuously without overexposure.

There are some holes in the bottom of the exposure cavity, and air is sucked through the cavity by the negative pressure existing at all times within the reactor. This keeps the cavity well ventilated. The cavity is at room temperature, ~25° C.

Fast neutrons. *Fast neutrons are obtained by placing a U^{235} fission plate in the exposure cavity of the thermal column. The plate is 17 cm in diameter and 0.1 cm thick, and absorbs 96% of the incident thermal neutrons. Actually, the U^{235} plate is placed in the bottom of one of the exposure boxes and then covered by a 1-inch-thick bismuth plate to filter out some of the fission gamma rays. The material to be irradiated is placed on top of the bismuth plate. The exposure box is then inserted into the exposure cavity in the usual way.*

The fission plate becomes very radioactive after even a short exposure, therefore, when the exposure is finished, the box is quickly brought to the end of the tunnel and the material quickly removed. The box is then pushed back in the tunnel and allowed to decay for about an hour. After this it is removed to a lead safe.

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enough so virtually no neutrons can penetrate, but which does not screen the gamma rays to any appreciable extent. A Victoreen condenser r-meter or National Bureau of Standards film cassette (*9*) is then placed inside the box to measure the gamma-ray dose rate. This method has two inherent errors. The first is that there are gamma rays associated with neutron capture in boron; these can be accounted for by running a lead absorption curve inside the box. The second is that the boron creates a neutron sink which decreases the neutron flux and consequently the gamma-ray contamination in the column; this one is accounted for with runs in large and small boron-carbide boxes. The gamma ray contamination as estimated by this method is probably of the order of 100 rep/hr.

The second method used is the lithium extrapolation method described by Brennan et al. (*10*). For this method, ionization chamber or film measurements are made inside a metallic lithium box which absorbs all the neutrons without the production of an associated gamma ray. The only error of the method is the neutron flux depression caused by the presence of the lithium. To take account of this error, boxes of pure lithium metal having different surface areas were made, each with walls at least $\frac{1}{8}$ in. thick.

The neutron flux inside these boxes was found to be negligible.

The ionization chambers used to measure the gamma rays here were Landsverk midget chambers having ranges of 5, 50, and 100 r. It was found that the wall thickness of these chambers was great enough to attain equilibrium with secondaries from Co^{60} gamma rays, and since the chambers were always surrounded by lithium, they must have been thick enough for equilibrium with secondaries of the 4–5-Mev gamma rays in the thermal column. In addition to the Landsverk chambers, films in special film holders designed by NBS (*9*), were used. These have been shown to be energy-independent from 150 kev to several Mev. Results obtained with the film are not as accurate as with the chambers, but are in essential agreement.

It was determined that the lithium shields produced virtually no attenuation of the gamma rays. The results of one such run are shown in Fig. 1.

The chamber readings are plotted against the surface area of the lithium boxes. On theoretical grounds one can show that if the gamma rays all originate as a result of neutron capture in graphite, and if it is an infinite graphite medium, then the plot of gamma dose rate vs. surface area should be a straight line and thus it should be possible to extrapolate accurately to zero surface area. However, it will be seen that these conditions are not fully met and so even beyond the point where the shields completely absorb all incident neutrons, the curve is not a straight line. In order to improve the extrapolation, lithium boxes with thinner walls were constructed and an estimate was made of the error in chamber reading caused by the known neutron leakage in each box. This correction was made and has been indicated on the graph. On this basis it is seen that the curve extrapolates to 115 rep/hr under these conditions. This value will, of course, depend upon the type of exposure box used and the neutron flux.

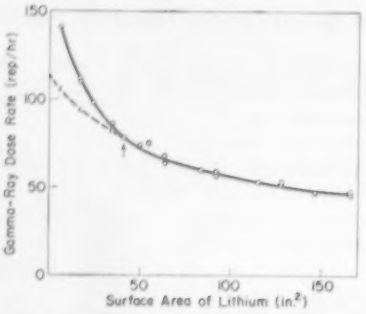

FIG. 1. Gamma-ray dose rate vs surface area of lithium absorber in the thermal column. Arrow indicates point at which total neutron absorption takes place

Graphite ionization chamber. A third method consisted of direct measurement of the gamma ray flux by means of a special ionization chamber constructed at this laboratory by Handloser and Olsen (*11*). This is a graphite chamber on the end of an 8-ft-long probe. CO_2 gas is kept flowing through the chamber during the measurements. These chambers are very insensitive to neutrons, but quite sensitive to gamma rays. A hole was drilled through the top shield and the removable graphite plug so the chamber could be inserted directly in the exposure box. The probe contained a guard ring to eliminate extraneous leakage and ionization, and was made of relatively low-cross-section material to eliminate the addition of more gamma rays. Currents were read on a special electrometer. The chamber was calibrated with a standard Co^{60} source.

Under the same conditions as were used for the lithium extrapolation measurements, a reading of 114 rep/hr ± 10% was obtained. This is obviously better agreement with the lithium extrapolation method than the accuracy warrants. The graphite ionization chamber method was by far the best of the methods used, although the design and construction of the chamber and associated apparatus was a research project in itself.

Using this chamber it was possible to measure the effect on the gamma ray contamination of putting various things in the exposure cavity. The most significant observation was that if the standard exposure box is left out, the gamma contamination drops to about 100 rep/hr, a decrease of 15%. (The box is a 7½-in. cube of ⅛-in. Lucite without a top.) This emphasizes the fact that the amount of extraneous material in the exposure cavity should be kept to a minimum.

The quality of the gamma radiation inside the exposure box was determined by taking a lead absorption curve inside the largest lithium shield using the Landsverk chambers. This absorption curve indicated that the energy of the gamma rays is about 3 Mev and quite homogeneous. This is about what one would expect if they all arise as a result of neutron capture reactions in graphite.

Neutron calibrations in the fast-neutron facility. The fast neutrons are formed in the U^{235} plate with the well-known fission spectrum. They then pass through 1 in. of bismuth, but this does not change the spectrum appreciably.

A certain number of thermal neutrons are not absorbed by the fission plate, and these will disturb the neutron energy spectrum. The graphite will reflect some fission neutrons with resultant degradations of energy.

It was felt necessary to estimate the neutron spectrum experimentally. This was done by exposing foils of known cross section and energy dependence, combined with appropriate shields, to monitor the neutrons in specific energy regions using the method of Hurst (*12*).

The foils used and results obtained are shown in Table 1, and the energy spectrum in Table 2. Also in Table 2 are the figures for the energy ranges covered for the fission spectrum obtained by graphic integration. It will be seen that about half of the neutrons

TABLE 1—Foil Measurements of Fast Flux

*Foil**	*Covering*	*Energy range*	*Reaction*	*Measured flux (10^8 n/cm²/sec)*
Au	none	0–1,000 ev	(n,γ)	4.56
Au	Cd	0.5–1,000 ev	(n,γ)	0.4
Pu^{239}	B^{10}	0.1 Mev	(n,f)	2.3
U^{238}	B_4C	1.5 Mev	(n,f)	1.03
S	none	2.5 Mev	(n,p)	0.16

* Measurements taken 3.5 in. above the center of the fission plate at 24-Mw power level. Thermal-neutron flux in the empty facility was 7.0×10^8 $n_{th}/cm^2/sec$.

are thermal or epithermal. The remainder are somewhat degraded from the fission spectrum, but not seriously so. The fast-neutron flux, considered as that part having an energy greater than 0.1 Mev, was 2.3×10^8 $n_f/cm^2/sec$ under these conditions.

From a biological point of view, fast neutrons having this spectral distribution are between 20 and 50 times more effective than thermal neutrons (Caldecott, *3*). Thus, if fast and thermal neutrons are present in about equal numbers, as they are in this facility, the thermal neutrons would contribute only about 5% to the total biological effect.

Thus, for biological purposes the neutron energy spectrum is essentially that of the fission spectrum, i.e., the majority of the neutrons have energies between 0.5 and 2.0 Mev.

For monitoring the facility it is convenient to use sulfur foils and to assume that the spectrum does not change with power level, etc. One can then multiply this reading by the appropriate factor to give the fast-neutron flux.

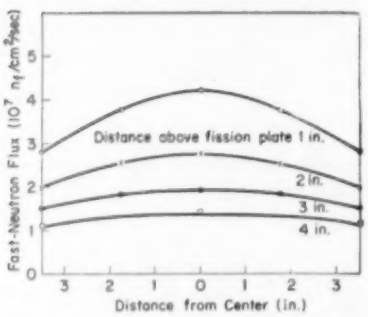

FIG. 2. Variation of fast-neutron flux across horizontal planes at various distances above the fission plate. Fluxes are measured by sulfur foils and are proportional to the total fast-neutron flux

The values of fast-neutron flux given are for a point 3.5 in. above the center of the plate. Unfortunately, the flux varies considerably as a function of position in the exposure box. This is shown in the curves of Fig. 2. The fast-neutron flux falls off very rapidly as a function of distance from the plate, but becomes much more uniform across a horizontal plane. The thermal-neutron flux increases slightly as a function of distance from the plate and is essentially constant beyond a distance of 2 in. There is thus considerable advantage in working at a distance of about 3 in. from the plate, even though the flux is considerably lower at this distance than at closer distances.

Gamma contamination in the fast-neutron facility. The gamma ray contamination has been measured by the graphite ionization chamber described earlier and found to be approximately 420 rep/hr.

TABLE 2—Fast-Neutron Spectrum

Energy range	*Flux* (10^8 $n/cm^2/sec$)	*Per cent of total flux*	*Per cent of flux above 0.1 Mev*	*Per cent of flux in fission spectrum*
0–0.5 ev	4.16	60.5	—	—
0.5–1,000 ev	0.4	5.8	—	—
0.1–1.5 Mev	1.27	18.5	55.0	50
1.5–2.5 Mev	0.87	12.7	38.0	24
2.5 Mev	0.16	2.3	6.9	26

Comparison with Other Facilities

The neutron fluxes indicated are fairly convenient for most biological work. An acute lethal dose of thermal neutrons to a mouse is delivered in about 1½ hours, and of fast neutrons in about 11 min. More resistant materials such as dry seeds require much longer exposures.

The gamma contamination is not very important from a biological point of view. Depending on the material under test, the gamma ray dose is 12–20% of the total biological effect in the thermal-neutron facility. In the fast-neutron facility it amounts to between 8 and 12%. These indicate that the facility does not constitute a pure neutron source, but seems to us to be a reasonable compromise.

There are only two other comparable facilities in this country. One is at Oak Ridge, where the thermal neutron flux is about 9.0×10^8 $n/cm^2/sec$ and the gamma ray flux is about 490 rep/hr (*8*). This high gamma contamination makes it of very limited usefulness from a biological point of view. The other is at the Los Alamos water boiler and has a neutron flux of 1.8×10^{10} $n/cm^2/sec$ and a gamma-ray flux of 1,480 rep/hr (extrapolation method).

On a comparable neutron basis, the gamma-ray contamination is about the same in the Brookhaven and Los Alamos facilities. In both cases the primary gamma rays from the reactor have been effectively shielded and the only gamma rays present are those from neutron capture in graphite, which are proportional to the neutron flux.

The fast-neutron facility of Argonne National Laboratory has been described by Vogel (*13*). It is patterned after the original fast-neutron facility at ORNL and uses natural uranium at the end of a thermal column as a fission source. The flux is roughly one-tenth the flux in the Brookhaven facility, and the gamma-ray contamination is about the same on a percentage basis.

Various types of particle accelerators have been used as fast-neutron sources for biological use. These have some advantages over the facility described here, notably in giving monoenergetic neutrons. However, in use the monoenergetic neutrons give rise, in biological materials, to protons having energies covering a very broad energy spectrum. Thus, except for very special cases, very little is to be gained by the use of monoenergetic neutron sources, and the ease, dependability, and accuracy of the facility described here make it far superior to accelerators for biological work.

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Slow-Neutron Capture Radioisotopes Arranged by Half-Life

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The accompanying table lists, in order of increasing half-life, the isotopes which are known to be produced by slow-neutron capture, excluding transmutation reactions. The half-lives of other isotopes of the same element that can be similarly produced by neutron irradiation are listed in parentheses after each entry. The table is useful in the identification of isotopes as, for example, for qualitative detection of trace-level impurities in a neutron-irradiated sample.

In practice, all of the isotopes of a given element will not be observed after neutron irradiation. One must consider the neutron energies involved, the cross sections for the particular reactions, the irradiation and decay times, and the relative efficiencies of the particular detection system for the various radiations and arrive at some estimate as to which isotopes will be detected under a given set of conditions.

To identify an unknown isotope completely, the usual procedures of characterizing the energy of the radiation and the chemistry of the element by carrier techniques are desirable.

This table has been compiled from data in BNL-325, Neutron cross sections (July 1, 1955).

$t_{1/2}$	*Isotope*
0.03 sec	B^{12}
0.85	Li^{8}
2.5	Er^{171} (9.4 d, 7.5 h)
7.4	N^{16}
11	F^{20}
13	In^{116} (49 d, 54.1 m, 72 s)
18	Se^{77} (123 d, 57 m, 17 m, 67 s, 25 m)
20	Sc^{46} (85 d)
24.2	Ag^{110} (2.3 m, 270 d)
29	O^{19}
40	Ne^{23}
44	Rh^{104} (4.5 m)
57	Ge^{77} (11.3 d, 82 m, 12 h)
67	Se^{83} (123 d, 18 s, 57 m, 17 m, 25 m)
72	In^{114} (49 d, 54.1 m, 13 s)
1.3 min	Sb^{124} (2.8 d, 21 m, 60 d)
1.3	Dy^{165} (2.32 h)
1.4	Ir^{192} (74 d, 19.0 h)
2.2	Zn^{71} (250 d, 13.8 h, 52 m)
2.27	Al^{28}
2.3 min	Ag^{108} (270 d, 24.2 s)
3.6 min	Cr^{55} (27.8 d)
3.6	Gd^{161} (230 d, 18.0 h)
3.76	V^{52}
3.9	Xe^{137} (5.3 d, 9.13 h)
4.2	Tl^{206} (2.7 y)
4.5	Rh^{104} (44 s)
5.0	S^{37} (87 d)
5.14	Cu^{66} (12.8 h)
5.5	Hg^{205} (47 d)
5.8	Te^{51}
6.6	Nb^{94}
8.5	Ca^{49} (152 d, 4.8 d)
9.5	Mg^{27}
10	Sn^{125} (112 d, 14.5 d, 250 d, 27.5 h, 40 m, 130 d, 10 d, >400 d)
10.4	Co^{60} (5.28 y)
14.3	Mo^{101} (6.9 h, 2.8 d)
16.4	Ta^{182} (111 d)
17	Se^{81} (123 d, 18 s, 57 m, 67 s, 25 m)
17.8	Rb^{88} (19.5 d)
18	Br^{80} (4.6 h, 35.9 h)
20.2	Ga^{70} (14.2 h)
21	Sb^{124} (2.8 d, 1.3 m, 60 d)
22 min	Pd^{111} (13.6 h, 17.0 d)
23.3 min	Th^{233}
23.5	U^{239} (2.4 × 10^{9} y, 7.1 × 10^{8} y)
24	Sm^{155} (400 d, 47 h)
25	Se^{83} (123 d, 18 s, 57 m, 17 m, 67 s)
25	Te^{131} (110 d, 58 d, 110 d, 9.3 h, 33 d, 72 m, 30 h)
25.0	I^{128}
31	Pt^{199} (4.3 d, 18 h)
37.5	Cl^{38} (3.08 × 10^{5} y)
40	Sn^{123} (112 d, 14.5 d, 250 d, 27.5 h, 130 d, 10 m, 10 d, >400 d)
49	Cd^{111} (6.7 h, 5.1 y, 43 d, 53 h, 2.9 h)
52	Zn^{69} (250 d, 13.8 h, 2.2 m)
54.1	In^{116} (49 d, 72 s, 13 s)
57	Se^{81} (123 d, 18 s, 17 m, 67 s, 25 m)
72	Te^{129} (110 d, 58 d, 110 d, 9.3 h, 33 d, 30 h, 25 m)
77	Kr^{87} (9.4 y, 4.4 h, 34.5 h)
82 min	Ge^{75} (11.3 d, 57 s, 12 h)

$t_{1/2}$	*Isotope*
85 min	Ba^{139} (12.0 d, 10 y)
1.8 hr	Yb^{177} (4.2 d, 32 d)
1.8	Nd^{149} (11.3 d)
1.82	A^{41} (35 d, 265 y)
2.32	Dy^{165} (1.3 m)
2.57	Ni^{65}
2.58	Mn^{56}
2.62	Si^{31}
2.80	Sr^{87} (65 d, 53 d)
2.9	Cd^{117} (53 h, 6.7 h, 49 m, 5.1 y, 43 d)
3.2	Pb^{209}
3.2	Cs^{134} (2.3 y)
3.7	Lu^{176} (6.8 d)
4.4	Kr^{85} (34.5 h, 9.4 y, 77 m)
4.5	Ru^{105} (2.8 d, 41 d)
4.6	Br^{80} (35.9 h, 18 m)
6.7	Cd^{107} (49 m, 5.1 y, 43 d, 53 h, 2.9 h)
6.9	Mo^{93} (2.8 d, 14.3 m)
7.5	Er^{171} (9.4 d, 2.5 s)
9.13	Xe^{125} (5.3 d, 3.9 m)
9.2	Eu^{152}
9.3	Te^{127} (110 d, 58 d, 110 d, 33 d, 72 m, 30 h, 25 m)
12	Ge^{77} (11.3 d, 82 m, 57 s)
12.4	K^{42} (1.3×10^9 y)
12.8	Cu^{64} (5.14 m)
13.6	Pd^{109} (22 m, 17.0 d)
13.8	Zn^{69} (250 d, 52 m, 2.2 m)
14.2	Ga^{72} (20.2 m)
15.0	Na^{24}
17.0	Zr^{97} (65 d)
18.0	Gd^{159} (230 d, 3.6 m)
18	Re^{188} (3.8 d)
18	Pt^{197} (4.3 d, 31 m)
19.0	Ir^{194} (1.4 m, 74 d)
19.2	Pr^{142}
24	W^{187} (140 d, 73 d)
27	As^{76}
27.3	Ho^{166}
27.5	Sn^{121} (112 d, 14.5 d, 250 d, 40 m, 130 d, 10 m, 10 d, >400 d)
30	Te^{131} (110 d, 58 d, 110 d, 9.3 h, 33 d, 72 m, 25 m)
31	Os^{193} (97 d, 16.0 d)
34	Ce^{143} (140 d, 32 d)
34.5 hr	Kr^{79} (4.4 h, 9.4 y, 77 m)
35.9 hr	Br^{82} (4.6 h, 18 m)
40	La^{140}
47	Sm^{153} (400 d, 24 m)
53	Cd^{115} (2.9 h, 6.7 h, 49 m, 5.1 y, 43 d)
63	Y^{90}
2.7 day	Au^{198}
2.8	Mo^{99} (6.9 h, 14.3 m)
2.8	Ru^{97} (41 d, 4.5 h)
2.8	Sb^{122} (21 m, 1.3 m, 60 d)
3.8	Re^{186} (18 h)
4.2	Yb^{175} (1.8 h, 32 d)
4.3	Pt^{193} (18 h, 31 m)
4.8	Ca^{47} (152 d, 8.5 m)
5.0	Bi^{210}
5.3	Xe^{133} (9.13 h, 3.9 m)
6.8	Lu^{177} (3.7 h)
9.4	Er^{169} (2.5 s, 7.5 h)
10	Sn^{125} (112 d, 14.5 d, 250 d, 27.5 h, 40 m, 130 d, 10 m, >400 d)
11.3	Nd^{147} (1.8 h)
11.3	Ge^{71} (82 m, 57 s, 12 h)
12.0	Ba^{131} (10 y, 85 m)
14.3	P^{32}
14.5	Sn^{171} (112 d, 250 d, 27.5 h, 40 m, 130 d, 10 m, 10 d, >400 d)
16.0	Os^{191} (97 d, 31 h)
17.0	Pd^{103} (13.6 h, 22 m)
19.5	Rb^{86} (17.8 m)
27.8	Cr^{51} (3.6 m)
32	Ce^{141} (140 d, 34 h)
32	Yb^{169} (4.2 d, 1.8 h)
33	Te^{129} (58 d, 110 d, 110 d, 9.3 h, 72 m, 30 h, 25 m)
35	A^{37} (265 y, 1.82 h)
41	Ru^{103} (2.8 d, 4.5 h)
43	Cd^{115} (6.7 h, 49 m, 5.1 y, 53 h, 2.9 h)
46	Fe^{59} (2.96 y)
46	Hf^{181}
47	Hg^{203} (5.5 m)
49	In^{114} (72 s, 54.1 m, 13 s)
53	Sr^{89} (2.80 h, 65 d)
58	Te^{125} (110 d, 110 d, 9.3 h, 33 d, 72 m, 30 h, 25 m)
60	Sb^{124} (2.8 d, 21 m, 1.3 m)
65 day	Sr^{85} (2.80 h, 53 d)
65 day	Zr^{95} (17.0 h)
73	Tb^{160}
73	W^{185} (140 d, 24 h)
74	Ir^{192} (1.4 m, 19.0 h)
85	Sc^{46} (20 s)
87	S^{35} (5.0 m)
97	Os^{185} (16.0 d, 31 h)
110	Te^{123} (58 d, 110 d, 9.3 h, 33 d, 72 m, 30 h, 25 m)
110	Te^{127} (58 d, 110 d, 9.3 h, 33 d, 72 m, 30 h, 25 m)
111	Ta^{182} (16.4 m)
112	Sn^{113} (14.5 d, 250 d, 27.5 h, 40 m, 130 d, 10 m, 10 d, >400 d)
123	Se^{75} (18 s, 57 m, 17 m, 67 s, 25 m)
129	Tm^{170}
130	Sn^{123} (112 d, 14.5 d, 250 d, 27.5 h, 40 m, 10 m, 10 d, >400 d)
140	W^{181} (73 d, 24 h)
140	Ce^{139} (32 d, 34 h)
152	Ca^{45} (4.8 d, 8.5 m)
230	Gd^{153} (18.0 h, 3.6 m)
250	Sn^{119} (112 d, 14.5 d, 27.5 h, 40 m, 130 d, 10 m, 10 d, >400 d)
250	Zn^{65} (13.8 h, 52 m, 2.2 m)
270	Ag^{110} (2.3 m, 24.2 s)
400	Sm^{145} (47 h, 24 m)
>400	Sn^{121} (112 d, 14.5 d, 250 d, 27.5 h, 40 m, 130 d, 10 m, 10 d)
2.3 yr	Cs^{134} (3.2 h)
2.7	Tl^{204} (4.2 m)
2.96	Fe^{55} (46 d)
5.1	Cd^{113} (6.7 h, 49 m, 43 d, 53 h, 2.9 h)
5.28	Co^{60} (10.4 m)
9.4	Kr^{85} (34.5 h, 4.4 h, 77 m)
10	Ba^{133} (12.0 d, 85 m)
12.4	H^3
265	A^{39} (35 d, 1.82 h)
5,570	C^{14}
3.1×10^5	Cl^{36} (37.5 m)
2.7×10^6	Be^{10}
2.4×10^7	U^{236} (7.1×18^8 y, 23.5 m)
7.1×10^8	U^{235} (2.4×10^7 y, 23.5 m)
1.3×10^9	K^{40} (12.4 h)

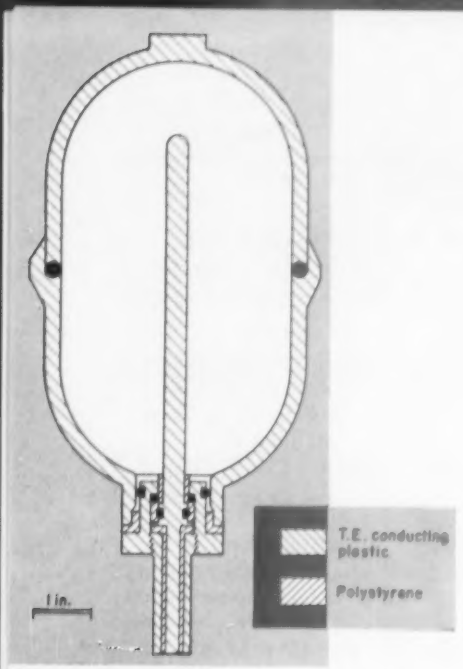

FIG. 1. Chamber used in protection surveys

Tissue-Equivalent Ionization Chambers

Here is the practical design information that made tissue equivalence something more than a theoretical principle—formulations for tissue-equivalent liquids, gases, and solids, construction techniques, filling procedures, and performance data

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TISSUE EQUIVALENCE has been discussed in principle (*1*) and in theory (*2*) in previous articles. Research on the design and construction of tissue-equivalent ionization chambers has been going on for a number of years and is still continuing. While some problems remain, it is desirable to describe the experience accumulated thus far.

Since these chambers contain in the walls and the gas the significant elements occurring in tissue in correct proportion, they may be used for the determination of absorbed dose of any ionizing radiation. The charge collected is related to the energy absorbed by the factor W (the average energy expended in the production of an ion pair). Since W varies little with the nature and energy of the primary ionizing particles, these chambers respond to a wide variety of radiations with essentially equal efficiency.

When radiations of different biological effectiveness (such as neutron and gamma rays) occur simultaneously, the biological effect to be expected will depend not only on the total dose, but also on the relative proportions of components of high and low specific ionization. To assess the contributions to the total dose according to specific ionization, additional information must be obtained. One approach is to modify the composition of the materials used in chamber construction. Thus, in addition to truly tissue-equivalent chambers, this work includes chambers which exhibit tissue-like response to some radiations, but are substantially insensitive to others.

Tissue-Equivalent Materials

The composition of soft tissue is somewhat variable, but a good typical approximation may be furnished by the formula $(C_6H_{10}O_5N)_n$. It is probably impossible to duplicate this composition by a mixture of solids at room temperature. However, a resilient gel of the desired composition may be compounded by the digestion at about 50° C of the following mixture (percentages by weight):

Water—66.2%
Gelatin—20.2%
Glycerol— 5.2%
Sucrose— 8.4%

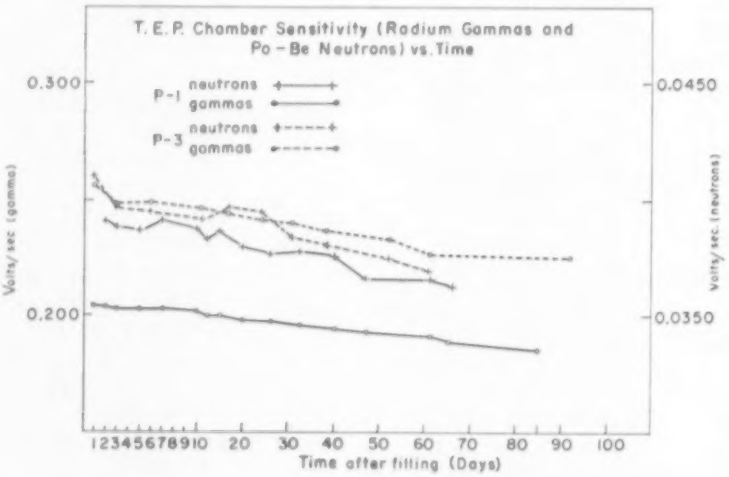

FIG. 2. Sensitivity of protection chamber as a function of time after filling

* Based on work performed under contract AT-30-1-GEN-70 for the Atomic Energy Commission.

Addition of ½% of formaldehyde results in a material of sufficient rigidity to serve as the lining of ionization chambers.

Because of evaporation such chambers must be hermetically sealed. This imposes no particular additional restriction since gas impermeability must be attained in any case because of the special gas filling required. However, the humidity inside the chamber is very nearly 100%, and this can lead to insulation difficulties. Nevertheless, it has been found that plastics of high resistivity (polystyrene, polyethylene, Teflon, fluorothene) provide very good insulation under these conditions, when they are thoroughly cleaned with mild soap and water and repeatedly rinsed with distilled water to make sure that all traces of detergent have been removed.

The gas in these chambers is also tissue equivalent. The desired composition may be obtained by a variety of mixtures of different gases. However, the gel dissolves carbon dioxide quite readily and this gas cannot be used to provide the bulk of the oxygen needed for the proper atomic composition. Therefore, oxygen is introduced as O_2. The mixture is explosive, but with normal care we have had no trouble on this account. A tissue-equivalent gas we have found satisfactory consists of the following mixture (percentages by partial pressure):

Hydrogen—38.1%
Methane —22.2%
Oxygen —37.6%
Nitrogen — 2.1%

Chambers employing these materials have shown excellent long-term stability and negligible leakage.

It will be noted that by using a gel it is possible to approximate the atomic composition of a tissue as closely as may be desired. Therefore, the interaction of ionizing radiation with the gel is essentially the same as it would take place in tissue, and ionization chambers of this type are satisfactory for the determination of absorbed dose of any ionizing radiation.

With some types of radiation satisfactory tissue equivalence may be obtained without exactly duplicating the atomic composition of tissue. Having developed the gel chamber, which could be used as a standard, it became possible to consider substitutes for the tissue-equivalent material. The desirability of using a plastic instead of the gel is obvious, but in this case most of the oxygen would have to be replaced by carbon. Since the neutron cross sections of these elements are rather similar over a wide energy range and the energy absorbed by these elements is small compared to that absorbed by the hydrogen in tissue, there was good theoretical justification for this approach.

The first attempt to compound such a plastic was made by one of us in 1945 by mixing powdered polyethylene, carbon, and ammonium nitrate in the desired proportions and then molding under pressure and heat. Tests indicated that the mixture was not quite homogeneous from the surface down, and that the conductivity was not always as high as desired. Therefore, when the problem was taken up again in 1949 it was decided to have the plastic prepared by the Markite Co.* The composition of this material is (percentages by weight):

Hydrogen	—10.1%
Nitrogen	— 3.5%
Carbon and traces of oxygen	—86.4%

In order to test the equivalence of the plastic and the gel, a series of experiments was performed at the Los Alamos Scientific Laboratory in 1950 in which gel and plastic chambers were exposed to neutrons of varying energies.† Since the hydrogen content of the gel was 9.7% and that of the plastic 10.1%, the chambers should have read in the ratio of 1:1.04, after applying second-order corrections for the response of the other elements. The actual readings observed at various neutron energies were as follows:

Neutron energy (Mev)	*Ratio*
0.5	1.10
1.0	1.05
2.5	1.07
14.0	1.05
Po-Be	1.04
Fission spectrum	1.05

The agreement is believed to be within experimental error.

The plastic as supplied by the Markite Co. has excellent conductivity. However, since no molding powder is available, it is necessary to machine chambers from solid blocks with considerable loss of plastic. Remolding of chips or shavings has led to very erratic results and in the majority of cases, insufficient conductivity was obtained.

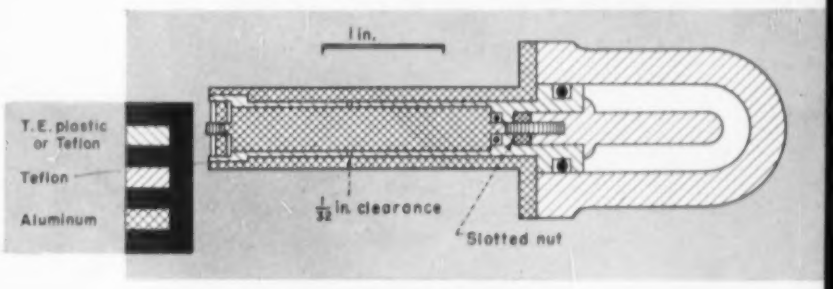

FIG. 3. Medium-sensitivity ionization chamber

A tissue-equivalent plastic that might be molded into any desired shape was produced by Federal Telecommunication Laboratories of Nutley, N. J. under AEC contract. This material may be molded at 275° F and pressures up to 2,000 psi. Molded pieces have good surface conductivity, but volume conductivity is usually low. Hence, little machining can be performed on molded pieces without interruption of critical conduction paths.

The tissue-equivalent plastic has substantially the same machining properties as polyethylene. Molds may be fabricated of either brass, steel, or a combination of these metals. Core pins should preferably be tapered (about 1 deg). However, whether straight or tapered, they must be withdrawn before the temperature of the plastic has dropped below 200° F, since marked contraction will crack the plastic or shrink it so tightly onto the

* Waverly Place, New York City.

† We are indebted to Dr. T. N. White for arrangements that made this work possible.

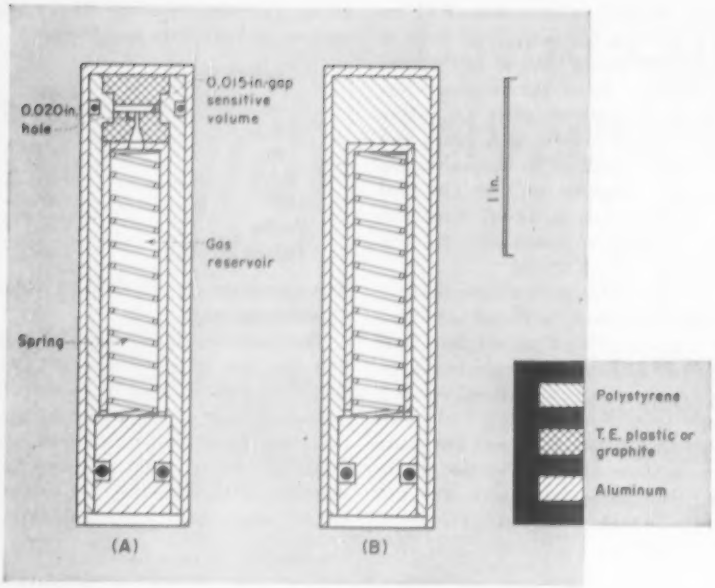

FIG. 4. High-dose chamber (A) and its dummy (B)

pin that removal without injury is impossible.

The main deficiency of the material is marked gas adsorption which, however, appears to be much less for molded than machined surfaces. Nevertheless, unless chambers have a high ratio of volume to surface, changes in internal pressure are likely to occur and the calibration is subject to long-term variation. Occasionally there is gas permeability as well, particularly for thicknesses of the order of $\frac{1}{8}$ in. or less.

The gas in the chamber should have the same atomic composition as the wall. Because the neutron response is insensitive to changes in the carbon-oxygen ratio, it is possible to use carbon dioxide as a major component of the gas and thus a nonexplosive mixture can be obtained. We have found the following mixture satisfactory (percentages by partial pressure):

Methane	—64.4%
Carbon dioxide	—32.4%
Nitrogen	— 3.2%

This mixture does not contain any electronegative gases, which facilitates saturation.

In depth-dose studies it is often desirable to move ionization chambers through a chemically inert tissue-equivalent liquid. A useful mixture (percentages by weight) is:

Water	—56.9%
Glycerol	—28.4%
Urea	— 7.6%
Sucrose	— 7.1%

Since water is the only ingredient having an appreciable vapor pressure, gradual losses due to evaporation may be compensated by occasional addition of water.

Special Wall Materials

For certain thermal-neutron measurements (see p. 36), special conducting plastics have been employed such as TE − N and TE + B. The former is a simple mixture of polyethylene and graphite, the latter, tissue-equivalent plastic to which known amounts of boron are added in a rubber mill of standard design.

In order to estimate contaminating gamma radiation, chambers have been constructed of graphite (or aquadag-coated Teflon) and filled with CO_2. In both cases, CO_2 absorption takes place (particularly initially) and routine X-ray calibrations are performed prior to use in the mixed radiation field. It has been found that loose graphite particles can often give rise to spurious chamber discharge. In the case of graphite electrodes, this effect can be minimized by heating electrodes until they are cherry red, quenching them in water, reheating them to drive off the

Dosimetry of Mixed Radiations

Biological objects exposed to slow neutrons are subject to radiation of three-fold origin. Thermal neutrons may react with the nitrogen in tissue giving rise to protons from the reaction $N^{14}(n,p)C^{14}$. In addition, capture by hydrogen, $H^1(n,\gamma)H^2$, gives rise to 2.2-Mev gamma rays. A third source of radiation consists of unavoidable contaminating gamma rays that are produced by capture processes originating in the vicinity of the biological object. A tissue-equivalent chamber will measure all three of these radiations with substantially equal efficiency. On the other hand, if both wall and gas are tissue equivalent except for the omission of nitrogen (TE − N) only capture and inherent gamma radiation will be recorded. If the wall is graphite or conducting Teflon and the gas CO_2, no significant capture will take place and the inherent gamma radiation only is recorded. Consequently, it is possible to determine the relative magnitude of the three components by subtraction of the readings obtained with the three chambers. If the tissues exposed contain elements of high capture cross section (such as boron) borated tissue-equivalent plastic (TE + B) may be utilized.

In the case of fast neutrons, hydrogen is by far the most important element in tissue, but energy taken up by the other light elements is not entirely negligible. Consequently, the graphite-CO_2 chamber will have a certain residual response, particularly at high neutron energies. Thus, an assessment of gamma contamination with this instrument is subject to somewhat uncertain corrections. Nevertheless, experience has indicated that useful information may be obtained even at comparatively high neutron energies and for this reason most of the tissue-equivalent ionization chambers described below have counterparts in which the sensitive volume is surrounded by conducting teflon or graphite and filled with CO_2.

water, and cooling them slowly, preferably in an atmosphere of CO_2.

Other Construction Materials

Chambers that are not exposed to significant fluxes of thermal neutrons can contain metal conducting members, provided these parts are not exposed to the ionizable volume. Aluminum has been used extensively because of its light weight, easy machining, and comparatively large thermal expansion coefficient, which more nearly approximates those of the plastics employed. Insulators have been fabricated from a variety of plastics. Minimal radiation-induced leakage appears to occur in polystyrene, particularly Monsanto P1X5.

Design Criteria

Since secondaries produced by neutrons have high specific ionization, it is desirable to design chambers for efficient ion collection. In cylindrical cavities the central electrode should have a fairly large diameter in order to reduce radial variation of the electric field. Sharp points and edges should be avoided. This also applies to inside corners where the electric field would be weak.

To minimize adsorption, it has been found highly desirable to expose only molded surfaces of conducting plastic to the collecting volume. High-dose chambers having small collecting volumes are made with built-in gas reservoirs.

To reduce gas diffusion through walls made of TE plastic, a minimum wall thickness of ¼ in. has been chosen in recent designs. For fast neutrons of energies up to about 20 Mev this represents somewhat more than an equilibrium thickness. Hence, such chambers will record essentially a "first-collision" dose. It is of course possible to design chambers that simulate absorption, scattering and build-up of external radiations and such designs have been employed, particularly in connection with thermal-neutron studies.

O-rings have been found to be very effective seals. However, because of comparative complexity of construction, efforts have been made to develop other methods of sealing. In particular, various techniques have been explored of molding insulating and conducting members in solid gas tight units. Efforts to bond metals to plastic dielectrics have not been too successful primarily because of differences in thermal expansion. Nevertheless, some chambers have been built in which aluminum and polystyrene were molded to form coaxial cylindrical elements involving aluminum casings of ½ in. o.d. and 1/16 in. wall and central conductors 3/16 in. in diameter with intervening space taken up by polystyrene. Careful annealing at 70° C eliminates cracking of the plastic.

More recent experiments have demonstrated the possibility of molding similar members made of conducting polystyrene and insulating polystyrene. The conducting polystyrene parts are molded at 275° C from a mixture of two parts (by weight) of powdered polystyrene and one part of graphite. Well-fitting insulators are also molded or machined. The parts are then assembled, placed in a closed mold and heated at 275° F. During heating the pressure may rise to more than 15,000 psi. Diffusion of graphite is so slight that layers of insulating polystyrene 1/16 in. thick are entirely satisfactory although they are bonded on either side to conducting polystyrene.

In some designs, TE chambers with polyethylene insulators have been heat-sealed as complete units with no other sealing techniques employed. Gas filling was accomplished by providing a small drilled hole through the polyethylene insulator, placing the entire chamber into an enclosure which could be evacuated and then filled with tissue-equivalent gas, and sealing the hole by means of a heating element inside the enclosure. A high degree of sealing could be achieved, but it is difficult to refill chambers of this type.

Survey Chambers

Fig. 1 shows the design of a chamber (P-Model) for personnel protection. Because of the high ratio of volume to surface, this model exhibits little change of internal gas composition as evidenced by its response to standard gamma and neutron sources. Fig. 2 indicates a slight drop of sensitivity over a period of time. Both P-1 and P-3 had been evacuated for about one hour and connected to a gas reservoir for about four hours prior to sealing. However, P-1 was filled in this manner for the second time while P-3 was filled for the first time. Hence, the variation with time is somewhat less for P-1. It is to be noted that for both chambers, neutron and gamma response vary in essentially the same manner. This indicates that the hydrogenous gas (methane) is adsorbed at about the same rate as the entire gas mixture. Thus changes in sensitivity to gamma rays as well as neutrons are equal and may be determined by the use of a small calibrating source. For this purpose we employ a 1-mg radium source placed on the cylindrical knob on top of the chamber.

This chamber embodies a guard ring and is sufficiently sensitive so that dose rates of the order of the maximum permissible rate for neutrons (0.75 mrads/hr for a 40-hr week) may be readily measured by means of standard electrometer circuits. Saturation voltage depends somewhat on the nature of the radiation and its intensity, but in practice 300 volts is usually satisfactory. This voltage appears across the large O-ring near the bottom of the chamber which acts both as gasket and insulator. This method of construction avoids the use of another O-ring, since a cylindrical insulator would have

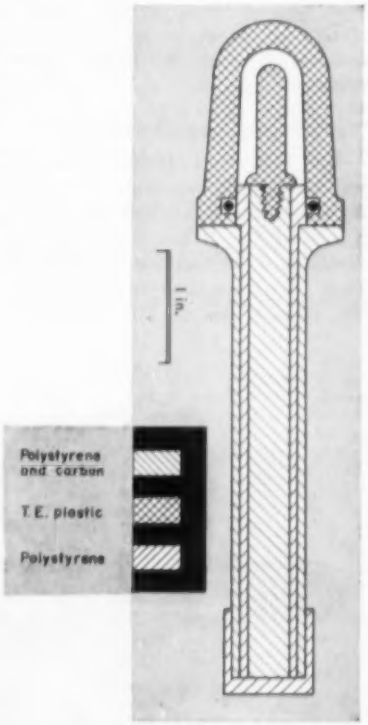

FIG. 5. All-plastic medium-sensitivity chamber

to be flanked on either side by O-rings. The internal pressure of tissue equivalent gas is about ½ atmosphere. Thus if a leak in the enclosure should develop, it would be readily detected when the chamber is tested with a standard source.

Y Chamber

Fig. 3 shows a chamber which has been used primarily to calibrate Victoreen chambers in order to determine the number of rads corresponding to one "n" unit (*3*). This chamber is filled by placing it in an enclosure with the thimble about ½ in. (axially) removed from the rest of the structure. The enclosure is evacuated for a period of several hours and filled with tissue-equivalent gas for a similar period. A mechanical member sliding into the enclosure through an O-ring is used to close the chamber. The pressure prior to sealing is adjusted so that the gas inside the closed chamber is at about 30 cm Hg. Because of the small volume, adsorption and permeation of the walls are more critical and the calibration may be expected to vary by a few percent per week. Hence, occasional refilling is mandatory. When used with the Victoreen condenser meter, this device has approximately the same neutron sensitivity as a 25-r Victoreen dosimeter.

Very-High-Dose Chambers

Fig. 4 shows a device (N-Model) utilized in determinations of exceedingly high doses (up to 4,000 rads).* The ionizable volume is a cylindrical cavity ¼ in. in diameter and 0.015-in. high. With the application of collecting voltages up to 730 volts, field strength of 18,000 volts/cm have been obtained without gas multiplication setting in. Because of the minute ionizable volume a comparatively large reservoir of gas is incorporated in the stem. Experiments have indicated that the sensitivity, nevertheless, varies at the rate of about 3% per week.

Further complications arise from the fact that at these high dose rates the dielectric becomes conducting. In addition, there appears marked charge transport across the dielectric. The value of the latter depends on the nature of the incident radiation, but does not change sign with applied voltage. This complication makes it necessary to perform simultaneous exposure of "dummies" (Fig. 4). These are generally similar structures in which the ionizing volume has been omitted. Since the dummy readings can become comparable to the readings of the ionization chambers and since some of the effects involved are thus far poorly understood, the uncertainty in such measurements is quite large.

Thermal-Neutron Measurements

Most metals exhibit appreciable capture cross sections for thermal neutrons and their use must be avoided in dosimeters. (Beryllium is an exception, but its fabrication involves severe health hazards.) The P-chamber discussed above is constructed entirely of plastic and consequently can be employed at locations where thermal-neutron fluxes are appreciable. Fig. 5 shows a chamber of low sensitivity (W-Model) that is also free of metal. Its stem is molded of parts containing both conducting and insulating polystyrene utilizing the technique mentioned above. The characteristics are quite similar to the ones of the Y chamber.

Fig. 6 shows an apparatus that has been employed in the thermal column of a water boiler. The thimble and center electrode of the ionization chamber have approximately the shape of a mouse, since doses received by mice were to be evaluated. Both electrodes are provided in three sets:

1. Tissue-equivalent plastic to determine the total tissue dose
2. Tissue equivalent plastic devoid of nitrogen to evaluate the sum of both capture and direct gamma radiation
3. Graphite, to assess the inherent gamma radiation only.

During measurement corresponding filling gases are used, *viz:* 1. tissue-equivalent gas, 2. tissue-equivalent gas devoid of nitrogen, and 3. CO_2. These gases may be introduced from outside the column and a gas mixer is provided to avoid layering of components. Supporting structures in the vicinity of the chamber are fabricated from Teflon, which has a negligible capture cross section. Aquadag coats provide conductivity. The connection between the collecting electrode and the electrometer is provided by means of a thin graphite rod that terminates in a thin steel wire, which in turn extends to the outside of the thermal column. To avoid ionization around this wire it is kept in an evacuated enclosure.

Fig. 7 depicts a device that is being

* Design and construction of these chambers was carried out in close cooperation with the Applied Physics Laboratory at St. Procopius College, Lisle, Illinois, under contract with the Atomic Energy Commission.

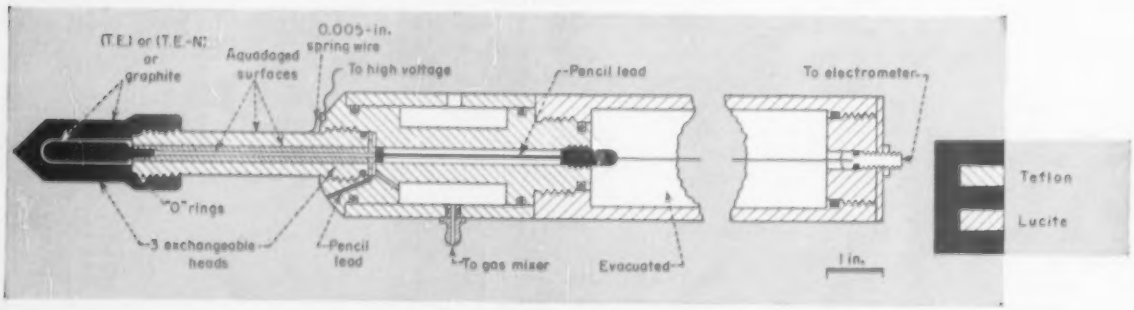

FIG. 6. Arrangement used to measure dose received by mice in a thermal column

used to determine depth doses in the Brookhaven thermal-neutron brain-tumor irradiation facility. Three ionization chambers are in a common envelope and axial rotation permits any of them to be brought into the same position with respect to a phantom filled with tissue-equivalent liquid. The three sets of plates are TE, TE − N, and TE + B, the latter to evaluate the additional energy absorbed due to known concentrations of boron in tissue. All three chambers have a common atmosphere of tissue-equivalent gas. The lack of precise wall equivalence in the TE − N and TE + B chambers is minimized by use of narrow gaps and extrapolation at low pressures. Because of the critical response of many gases to thermal neutrons the device is also connected to a large external reservoir and recirculation can be accomplished with pressure differentials. The three chambers are connected to external electrometers by means of polyethylene cables.

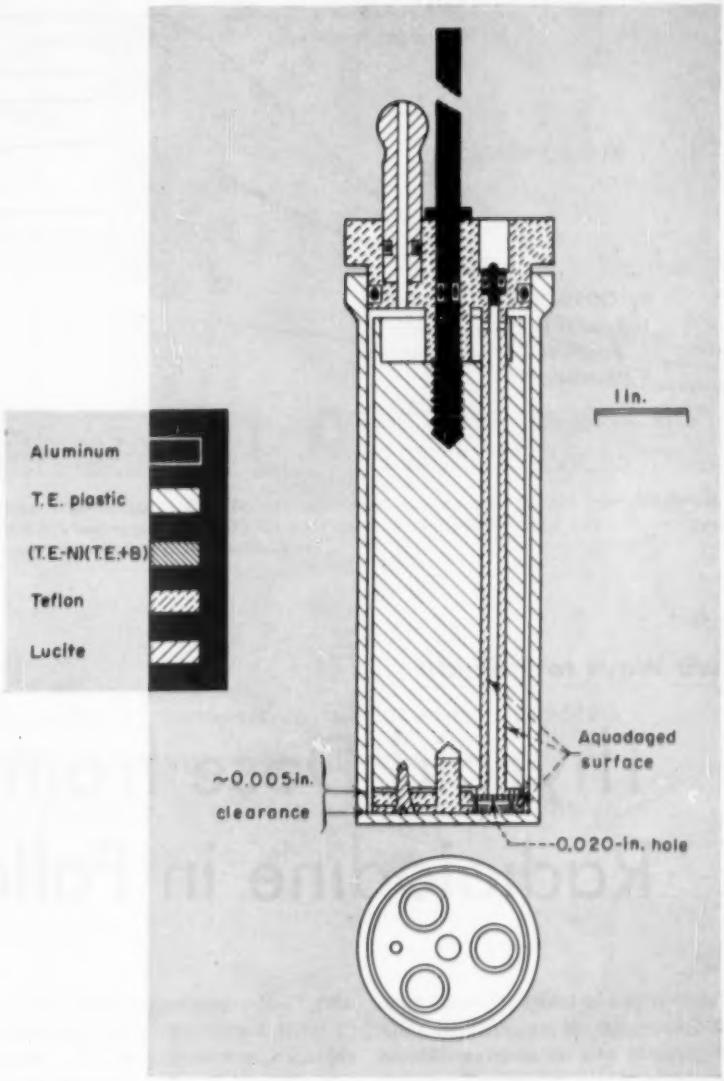

FIG. 7. Chamber used to determine depth doses of thermal neutrons

Calibration

When tissue is exposed to 1 r of reasonably hard electromagnetic radiation, it is generally assumed that 93 ergs are absorbed per gram. Consequently, calibration of tissue-equivalent ionization chambers may be performed by exposing them to known amounts of well-filtered (2-mm Cu) radiation from conventional X-ray therapy machines (over 200 kv). Because of the 10 percent difference in W for electrons and protons, an equal deflection in a pure neutron field represents a somewhat higher energy absorbed (102 ergs/gm*). Since the currently accepted unit of tissue dose is the "rad," representing 100 ergs/gm, a 2% correction is applied to obtain the response to 1 rad of neutrons from the observed response to 1 r of X-rays. Thus, if exposure to 1 r results in a reading, A, the sensitivity of the chamber is 0.98 A divisions per rad of neutrons. In the case of mixed radiation fields, allowance is made for the relative proportion of electrons and heavy particles up to a maximum variation in W of 10%.

When tissue-equivalent and CO_2 chambers are exposed to a mixed radiation field, and the deflection of either instrument when exposed to 1 r of X-rays is taken as 1, then

$$T = 0.98N + 1.07\Gamma$$
$$C = KN + 1.07\Gamma$$

where T and C are the deflections of the tissue-equivalent and CO_2 chambers respectively and N and Γ the doses in rads delivered by neutrons and gamma rays.

K is a factor that depends on neutron energy. Theoretical computations as well as practical experience indicate that it ranges from about 0.05 at 0.5 Mev to 0.25 at 14 Mev. At energies below 100 kev, K should be substantially zero.

* Recent experiments have indicated that the difference in W may be less than 10%. Consequently, it may be necessary to employ a correspondingly smaller correction factor.

Much of this work has been made possible because of the help of a considerable number of investigators who have assisted us over a period of several years. We should like to express our indebtedness to Dr. R. K. Clark, William Gross, Dr. S. Whitcher, Dr. Amos Norman, R. H. Ellis, Jr., Dr. B. M. Dwork, Sidney Talesnick, Walter Rosenzweig, Marvin Lubert, and Marvin Feldman.

Recent work has been performed in close cooperation with Dr. Francis Shonka and his staff at the Applied Physics Laboratory at St. Procopius College, Lisle, Illinois.

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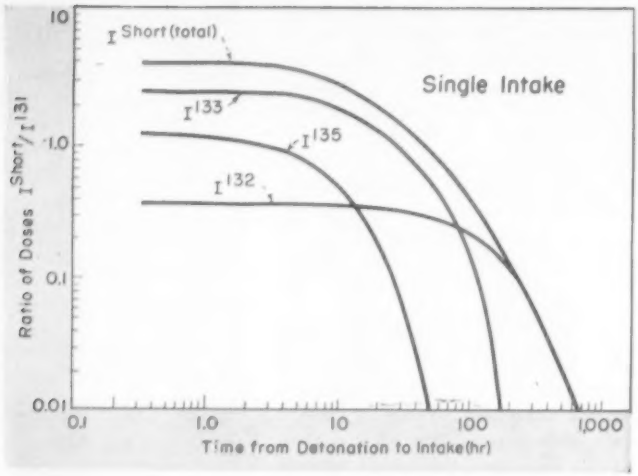

FIG. 1. Approximate ratio of infinity dose to thyroid from short-lived radioiodine isotopes and I^{131} for case of single intake. See Table 2 for sample calculation of these curves

Two Ways to Estimate

Thyroid Dose from Radioiodine in Fallout

CALCULATING RADIATION DOSE from fallout presents unique problems. One of these is how to estimate thyroid dose from intake of the radioisotopes of iodine found in fallout material. Because of uncertainties in the relevant variables, the calculations cannot be made with the precision that is possible in a laboratory or clinical situation. However, it is often essential to make such estimates, even though admittedly based on limited data.

There is disagreement as to the principal mode of entry into the body of the radioactive I contained in fallout, i.e., inhalation or ingestion. For low-yield detonations, such as in Nevada, relatively higher concentrations of fallout material are found in the air for only a matter of a few hours with essentially all of calculated intake by inhalation completed within 24 hours for nearby communities.

When the detonations occur at the Pacific proving ground the activity in the air may persist for somewhat longer times in the U. S. Thus, for relatively early, short exposures the amount of intake by inhalation may be comparable to that by ingestion. However, if one considers normal ingestion for a continuing period, it would appear this is by far the dominant factor. This is especially true for grazing animals. In fact, field experiments near the Nevada test site showed there was little I in the thyroid of rabbits, who were restrained so that they could not ingest any material but could continue to inhale during and after fallout.

The problem of dosage calculations is complicated by the presence, at early times after detonation, of short-lived I isotopes in addition to I^{131} and by tellurium precursors for several.

The general approach given below for these problems is to calculate the dose from I^{131} and its precursors and then add to this the contribution from the short-lived isotopes of I and their precursors. Due to relative abundance or short half-lives the only isotopes of concern here are: I^{131}, I^{132}, I^{133}, I^{135}, Te^{131m}, Te^{131}, Te^{132}, and Te^{133}. Their properties are given in Table 1.

Calculating Dose

The precise calculation of I^{131} intake to the thyroid is difficult because of

a. Uncertainties of the percentage of intake into body that reaches the thyroid.
b. The tellurium precursors that result in the absolute activity of the I^{131} in the environment remaining roughly constant for about a day followed by a period of increasing decay rate until the precursors no longer play a significant role and the decay rate then becomes that of I^{131}.

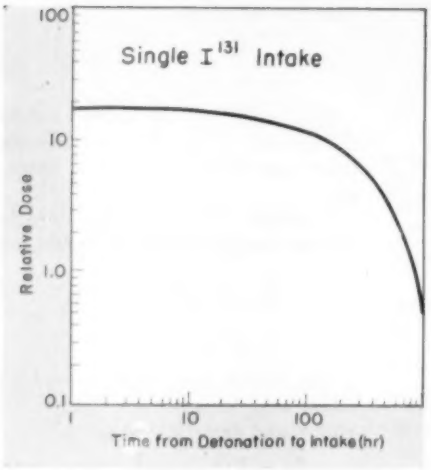

FIG. 2. Approximate infinity dose to thyroid from single intake of the I^{131} and its tellurium precursors from 10,000 fissions. This figure is used with Table 3 in the preparation of Fig. 3

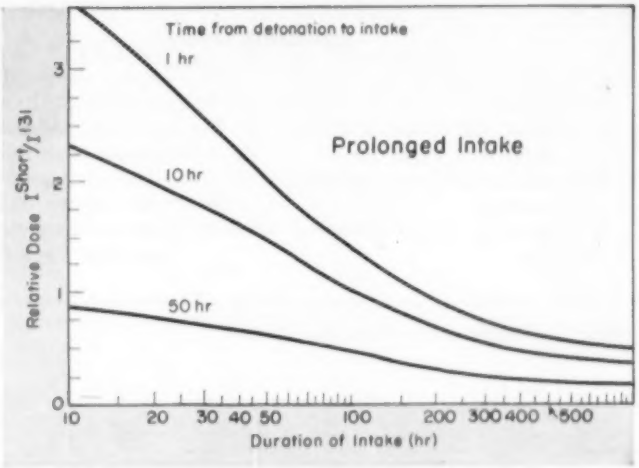

FIG. 3. Approximate relative infinity dose to thyroid from short-lived I isotopes and I^{131} for case of prolonged intake. See Table 3 for sample calculation of these curves

When ingestion or inhalation of radioactive fallout material occurs, it is important to be able to estimate the dose received. Here, for the case of radioiodine, is a procedure for determining the thyroid dose given present activity or initial intake

c. The intake, along with the I^{131}, of Te^{131m}, a part of which will disintegrate within the body to I^{131}.

To estimate the original rate of intake of I^{131} from a known activity in the thyroid at a later date, one can extrapolate according to the physical and biological decays of I^{131} only. This method ignores intake factor **b** and thus overestimates the original intake; it also ignores factor **c** and thus underestimates the original intake. The extent to which these affect the answer depends upon time of original intake after detonation and the duration of intake. However, estimates of the effects of ignoring these two factors indicate that the over-all error would not be any greater than other inherent uncertainties.

The exact steps are given in the following sections. The symbols are defined at the head of page 40. Two examples are given on pages 40 and 41.

1. Initial rate of intake of I^{131}, R_0. Assume that the rate of intake decreases according to the physical decay of the isotope. Then activity in the thyroid changes with time thusly

$$\frac{dA}{dt} = R_0 e^{-\lambda_r t} - (\lambda_r + \lambda_b)A$$

TABLE 1—Isotopes Important to Thyroid Uptake

Mass number	*Atomic number* 51 (*Sb*)	52 (*Te*)	53 (*I*)	54 (*Xe*)	55 (*Cs*)
131		30 hr ↓			
		25 min →	8.0 day →	stable	
132		~5 min → 77 hr →	2.4 hr →	stable	
133		<10 min → 60 min →	21 hr →	5.3 day →	stable
134		<10 min → 43 min →	50.8 min →	stable	
				15.3 min (~10%) ↗	
135		<1 min →	6.7 hr		
				↘ 9.2 hr →	2.1 × 10^6 yr → stable

Symbols Used

$A = A(t)$ = activity in thyroid (μc/gm)
R_0 = initial rate of intake of thyroidal I^{131} (μc/gm/day)
λ_r = radiological (physical) decay constant
λ_b = biological decay constant
t = time
E = average energy of beta particles (Mev)
K = 55 R_0E (a constant)
D_∞ = infinity dose (reps) to thyroid from single I intake
D_t = total infinity dose (rep) to thyroid from continual intake from $t = 0$ to $t = \infty$.

TABLE 2—Sample Calculations for Figure 1

A	B	C	D	E	F	G	H
Radioisotope	Half-life (hr)	Activity[a] (dpm/10,000 fissions)	Number of atoms present per 10,000 fissions	Atoms of iodine reaching thyroid per 10,000 fissions	Average beta energy (Mev)	Max. rel. energies to thyroid ($E \times F$)[b]	Ratio[c] $\frac{I^{short}\ Energy}{I^{131}\ Energy}$
I^{131}	192	0.014	230	57.5[d]	0.20	11.5	
Te^{131}	30	0.019	49.4	9.9[e]	0.20	1.9	
Te^{131m}	0.42	1.5	54.3	13.6[f]	0.20	2.7	
I^{132}	2.4	0.026	5.4	0.3[g]	0.52	0.16	0.01
Te^{132}	77	0.056	374	11.2[h]	0.52	5.8	0.36
I^{133}	21	0.14	255	48.5[i]	0.45	21.8	1.35
Te^{133}	1	2.6	226	43.0[j]	0.45	19.4	1.20
I^{135}	6.7	0.88	512	61.6[k]	0.30	18.5	1.15
I(all short-lived)							~4.07

[a] Based on Hunter and Ballou tables (*1*).

[b] The biological fate of the isotopes of iodine is the same. Thus, the same proportions of the total number of atoms of each are taken into the thyroid and then eliminated according to the biological characteristics of the animal. The loss of an atom of a short-lived isotope means a greater loss of energy to the thyroid than does the loss of an I^{131}. However, it is to be expected that the biological half-life of animal thyroids will be much greater than the radiological half-life of even the longest short-lived radioiodine isotope (I^{133} with 21-hr half-life) so that essentially all of these energies will be delivered to the thyroid. For cases where the biological decay constant, λ_b, is significantly large compared with the radiological decay constant, λ_r of I^{131}, (0.0036 hr^{-1}), then the values for energies of I^{131} (including Te^{131} and Te^{131m} precursors) given in column *G* should be multiplied by the factor $\lambda_r/(\lambda_r + \lambda_b)$ and likewise the values for the relative energies in column *H* for the short-lived isotopes should be multiplied by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

[c] All of the iodine atoms reaching the thyroid will disintegrate there. Corrections may be necessary according to footnote *b*.

[d] 25% of the I^{131} atoms taken into the blood reach the thyroid.

[e] 20% of Te^{131m} taken into the body reaches the thyroid, i.e., about 80% would have disintegrated to Te^{131} while in the gut of which all disintegrates to I^{131} of which 25% reaches the thyroid.

[f] All of the Te^{131} atoms taken into the body will disintegrate to I^{131} of which 25% will reach the thyroid.

[g] 6% of the I^{132} taken into the body reaches the thyroid. The biological half-life of I in the blood of humans may be about 7 hr (*2*). According to available data to date (*3*) the biological half-life of I in the blood of sheep may be 10–12 hr for the first day, followed by a flattening out of the curve. The proportion of activity reaching the thyroid may be estimated as $\frac{1}{4}\lambda_B/(\lambda_B + \lambda_r)$. The values in Table 1 are based on human data (7-hr biological half-life of iodine in the blood). These also give approximate values for sheep. Assuming a biological half-life of iodine in the blood of sheep of 11 hours over a period of 22 hours only, the ratios given in Fig. 1 differ for sheep as follows: I^{132}, about 30% too high; I^{133}, 10% too low; I^{135}, 10% too low. The ratio of doses from individual short-lived iodine isotopes indicated in Fig. 1 suggests that the ratio of the total short-lived isotopes to I^{131} may be underestimated for sheep by a few per cent in the early times after detonation. At later times the I^{132} contribution predominates, but also the ratio of infinity doses from the total short-lived isotopes to I^{131} has decreased significantly. Thus, the method suggested here may give a fair approximation of the total infinity doses for sheep.

[h] 3% of the Te^{132} intake reaches the thyroid as I^{132}, i.e., 50% would disintegrate to I^{132} while in the gut of which 6% will be deposited in the thyroid per footnote *g*.

[i] 19% of the I^{133} taken into the body will be deposited in the thyroid; 25% would be deposited normally, but about 25% of these atoms will decay before deposition[g].

[j] All of the Te^{133} taken in will disintegrate into I^{133} while within the body of which 19% will reach the thyroid according to footnote *i*.

[k] 12% of the I^{135} intake will be deposited in the thyroid; 25% would be deposited normally, but about 50% will decay before deposition according to footnote *g*.

This has the solution

$$A = \frac{R_0}{\lambda_b}\left(e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}\right) \qquad (1)$$

Thus, analyzing the thyroid for its I^{131} activity, A, at any time, t, one can figure back to the initial rate of intake, R_0.

2. Infinity I^{131} dose. The dose to infinity from I^{131} intake on the first day is

$$D_\infty = K\int_0^\infty e^{-(\lambda_r+\lambda_b)t}\,dt$$
$$= K/(\lambda_r + \lambda_b)$$

The infinity dose from a continuing intake that decreases according to the radiological decay is then given by

$$D_t = K/\lambda_r + \lambda_b\int_0^\infty e^{-\lambda_r t}\,dt$$
$$D_t = K/(\lambda_r + \lambda_b)\lambda_r \qquad (2)$$

3. Doses from short-lived isotopes. The additional dose to the thyroid from short-lived isotopes of iodine resulting from a *single* intake is summarized in Fig. 1. A sample of the calculations used to construct Fig. 1 is given in Table 2 at left.

In the case of grazing animals, however, the period of intake may start at different times after detonation and extend for varying periods of time. An estimation of additional doses to the thyroid from short-lived isotopes of iodine under these conditions is summarized in Fig. 3. A sample of the calculations used to construct Fig. 3 is given in Table 3.

Example: Sheep Ingestion

About 3½ hours after the nuclear detonation at the Nevada Test Site on May 19, 1953, fallout occurred in an area around Cedar City, Utah, where sheep were grazing. On June 15 some of these sheep were sacrificed and on July 8 the I^{131} concentrations were measured in specimens of their thyroids. The highest measured I^{131} concentrations on July 8 were about 5×10^{-2} μc/gm (c.f. *3*). What might have been the total radiation dose to the thyroids of these sheep from all of the isotopes of radioiodine?

First calculate the I^{131} dose, then the dose from short-lived isotopes. Determine the initial rate of intake of I^{131} activity per gram, R_0 from Eq. 1

$$A = (R_0/\lambda_b)[e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}]$$

In this case $A_b = 0.37$ μc/gm when sacrificed June 15. (Working back

from July 8 measurement.)

t = 27 days (May 19–June 15)

$\lambda_r = 0.0866\ \text{day}^{-1}$

$\lambda_b = 0.0204\ \text{day}^{-1}$*

Thus

$$0.37 = \frac{R_0}{0.0204}\left[e^{-(0.0866)27} - e^{-(0.107)27}\right]$$

$R_0 = 0.189\ \mu\text{c/gram/day}.$

Now we determine the infinity I^{131} dose using Eq. 2.

$$D_{t\infty} = K/\lambda_r(\lambda_r + \lambda_b)$$

where: $K = 55$ $R_0E = 55(0.189)(0.2) = 2.08$

Thus $D_{t\infty} = 224$ reps is the infinity I^{131} dose.

To estimate the dose from short-lived isotopes of I enter Fig. 3 with these parameters:

start of intake = 3.5 hr

duration of intake = infinity.

The graph indicates a ratio of approximately 0.45.

But this is uncorrected for biological decay, i.e., it is based on the assumption that the biological decay constant for the thyroid is significantly less than the physical decay constant. It is necessary to correct this ratio by multiplying by the factor†

$$(\lambda_r + \lambda_b)/\lambda_r = 1.24.$$

$$0.45 \times 1.24 = 0.557$$

The infinity dose to the thyroid from short-lived isotopes of iodine is this fraction of the I^{131} dose

$$224 \times 0.557 = 125\ \text{rep}.$$

Thus the total infinite dose is $224 + 125 \cong 350$ rep.

This is not considered dangerous. Experimental studies with sheep at Hanford Atomic Products Operation suggest that about 16,000 reps are required to produce minimal changes in the thyroid cellular structure and about 50,000 reps to produce definite cell damage and hypothyroidism.

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* Biological half-life in sheep thyroids is about 34 days (4).

† See footnote *b* Table 2.

EXAMPLE: Human Inhalation

On May 19, 1953 the highest concentration of activity in the air due to fallout that has ever been recorded in the U. S., outside the Nevada Test Site, occurred at St. George, Utah. It amounted to about 1.3 $\mu c/m^3$ averaged over 24 hours. The total radiation dose to the thyroids of the people at St. George from inhalation of the isotopes of I is estimated to be 0.302 rep as shown in the following tabular calculation.

Estimate of Radiation Doses to Thyroid of Humans From Inhalation

Time after detonation (hr)	*Average fission-product activity ($\mu c/meter^3$)*	*Fission-product activity originally retained (μc)[a]*	*Fraction of fission product that is I^{131} %*	*I^{131} activity reaching thyroid (millimc)*	*Infinity I^{131} dose to thyroid (rep)[d]*	*Added dose from short-lived I isotopes[e] (rep)*	*Total infinity dose (rep)*
2–7	4.0	12.4	0.16	5.00	0.0304	0.121	0.155
7–10	2.3	4.3	0.35	3.77	0.0230	0.074	0.097
10–14	0.62	1.56	0.47	1.80	0.0110	0.030	0.041
14–18	0.043	0.104	0.7	0.19	0.0012	0.003	0.004
18–30	0.014	0.105	1.1	0.29	0.0018	0.003	0.005
						Total	0.302 rep

[a] Based on 0.83-$meter^3$/hr air intake and assuming that 75% of the activity will be initially retained either in the lungs or find its way into the gastrointestinal tract.

[b] Based on assumption that 75% of initial intake of both Te precursors of I^{131} will remain within body until decayed to I^{131}.

[c] Assuming 25% of initial retention of I^{131} (either in lungs or gastrointestinal tract) reaches the thyroid.

[d] Initial dose rate = (55)(0.2)(μc of I^{131} per gram of tissue) in reps per day. Infinite dose = Initial dose rate/$(\lambda_r + \lambda_b)$.

[e] From Fig. 1. Multiply these ratios by $(\lambda_r + \lambda_b)/\lambda_r$ for I^{131} in man.

TABLE 3—Sample Calculations for Figure 3

A	*B*	*C*	*D*	*E*	*F*	*G*
Periods of intake (hours after detonation)	*Relative mean I^{131} energy intake × hours in period[a]*	*Cumulative I^{131} energy intake*	*Mean of ratios of energies I^{Short}/I^{131}*	*Relative energy I^{Short} (Columns B × D)*	*Cumulative I^{Short} energies intake*	*Ratio of total energies I^{Short}/I^{131} for infinite thyroid dose intake from 1st hour to end of period indicated (Column F ÷ C)[c]*
1–11	160	160	3.6	575	575	3.6
11–21	158	318	2.3	364	939	2.95
21–31	150	468	1.6	240	1,179	2.52
31–41	146	614	1.3	190	1,369	2.23
41–51	140	754	1.0	140	1,509	2.0
51–61	135	889	0.84	115	1,624	1.83
61–71	130	1,019	0.70	91	1,715	1.68
71–81	125	1,144	0.55	69	1,784	1.56
81–91	120	1,264	0.46	55	1,839	1.45
91–101	115	1,379	0.40	46	1,885	1.37
101–201	920	2,299	0.20	184	2,069	0.900
201–301	650	2,949	0.08	52	2,121	0.718
301–401	470	3,419	0.042	19	2,140	0.626
401–601	600	4,019	0.02	12	2,152	0.535
601–801	280	4,299	0.0095	3	2,155	0.500
801–1,001	140	4,439	0.005	1	2,156	0.484

[a] Based on Fig. 2.

[b] From Fig. 1.

[c] This is uncorrected for biological decay as described in footnote *b*, Table 1. For cases where biological decay in the thyroid is significant for I^{131}, multiply last column *G* by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

Thermonuclear Power . . .

NUCLEONICS here offers two views of thermonuclear work going on. The first are photographs of Princeton University's Project Matterhorn and what can be told about activities there. Very little can be said about the research itself. The second shows unclassified research at other laboratories on ultra-high-temperature gas discharges, one of the crucial problems for the attainment of controlled fusion power. This research is not centrally directed, is not aimed specifically at the goal of achieving fusion power. Still, it could be an example of the kind of independent activity that might result in significant

1. Research in Secret

In a rabbit hutch and a horse operating room formerly used by the Rockefeller Medical Institute, a strikingly young and enthusiastic Princeton group is busy trying to tame the thermonuclear reaction for peaceful power.

There is now a fairly good sized group working on Project Matterhorn —the Princeton sector of Project Sherwood. They are divided into a theoretical group, an engineering group, an experimental group, and a support group of technicians and secretaries. AEC will not allow disclosure of the approximate number in each group, but the Princeton University catalogue lists the names of about 40 professional people assigned to Project Matterhorn. Their average age is about 33; Dr. Lyman Spitzer, who heads Matterhorn, is 41. They work in many fields and success in any of them will represent a technical achievement in itself. Among these fields are microwaves, spectroscopy, high-vacuum technology, gas discharges, high-power studies, pulse electronics, and plastic and metal research.

The effort is now the biggest project at Princeton, and although AEC furnishes the funds, Princeton is in administrative charge and does the hiring—at university salaries but with university privileges. Some of the people are on loan from industry, but under an agreement that they are not to report any of their experience back to their parent company. The company gains only the eventual benefit of their experience on Matterhorn—and the satisfaction of serving the country. Princeton reports that the hiring problem has been eased considerably by AEC's announcement of work in this field. However there may still be a handicap in that many bright young people refuse to work behind a barrier.

Matterhorn people can say next to nothing about the technical aspects of their work, and giving just the nickname of one of their devices amounted to a major revelation. This is the "Stellarator"—an obvious combination of star and accelerator. However visitors to Matterhorn's "campus" 3 miles northeast of Princeton note the absence of any very large structures, which seems to suggest that no conventional accelerators are being used. (A $500,000 building going up adjacent to the rabbit hutch will provide additional experimental space by midsummer.)

FIG. 1. The former rabbit hutches that now house Project Matterhorn. At right are the foundations for the new lab being built expressly for the fusion-power project

FIG. 2. Only visitors with Matterhorn clearance are permitted inside the buildings. The guards, who obligingly lined up for NUCLEONICS' photographer, are normally inside

. . . The Search for Ideas

future contributions. It certainly serves to make more concrete the type of experimental problems faced in exploring thermonuclear power.

We hope this article will serve to satisfy curiosity as to what Matterhorn looks like, that it will arouse curiosity as to what goes on within its guarded doors. We think the unclassified work demonstrates that fusion reactors will be very different from fission reactors. It follows that there will be a lot of learning to do if controlled thermonuclear power is realized. That adds a reason why there ought to be freer discussion of thermonuclear power.

2. Research in the Open

In two cellar laboratories four miles apart in Boston's suburbs, and on a university campus on the West Coast, scientists are working in the same fields independently of AEC but on closely parallel lines. Their work is unclassified.

Thus, in spite of AEC's reticence, the broad outlines of the technical problems involved are becoming apparent. In particular, the behavior of matter at very high temperatures—tens of millions of degrees—needs to be studied. For it is only by bringing substantial numbers of deuterons to these temperatures that one can hope to achieve enough exoergic reactions to gain back the energy expended in getting things that hot. At these extraordinary temperatures, well past the vaporization point of all materials, matter becomes a highly ionized gas, or plasma.

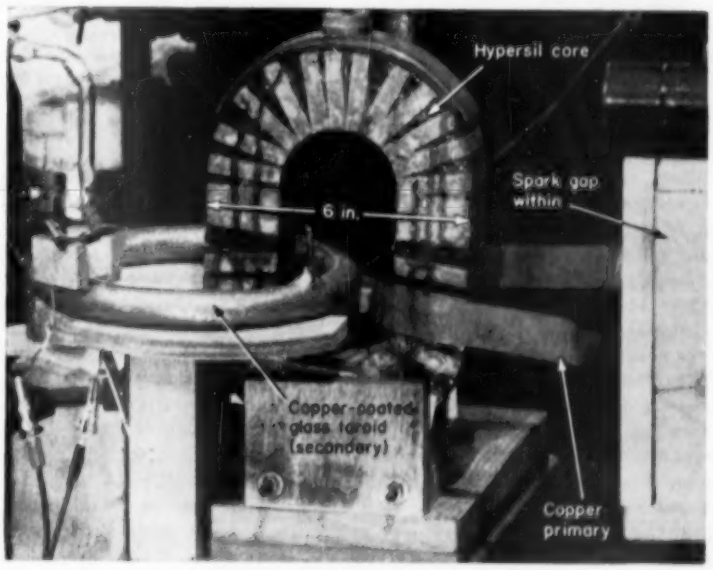

FIG. 3. Apparatus used by R. E. Vollrath of U. S. C. to observe the pinch effect. A 150-μf condenser charged to 5,000 volts is discharged through a spark gap in series with single turn of copper ribbon shown. This forms the primary of a transformer whose secondary is a copper-coated glass toroid filled with hydrogen at 1 mm pressure. Currents of 5,000 amperes are observed in the discharge

Some of the technical regions now being explored by large groups of scientists in AEC's top-secret Project Sherwood had been scanned much earlier by individuals with varied interests and goals. This is not surprising in view of the unplanned, almost random, path and great variety of scientific investigation. What is surprising is that there has not been *more* research on the nature of matter at high temperatures, for most of the universe is plasma; only a few cool planets and moons and interstellar space contain matter in the forms to which we are accustomed. Even the upper atmosphere of the earth is highly ionized (because of the radiation passing through it). Of course, ionized plasmas have long been produced by gas-discharge researchers.

Thus it is that astrophysicists, geophysicists and physical-electronics experts were concerned with ionized matter long before Project Sherwood was conceived, and that many of the leaders of Sherwood hail from these disciplines. A selected bibliography on high-temperature gas discharges is given at the end of this article (*1–13.*)

Unclassified Research

Not all present work in the field of high-temperature gas discharges is classified. For example the pinch

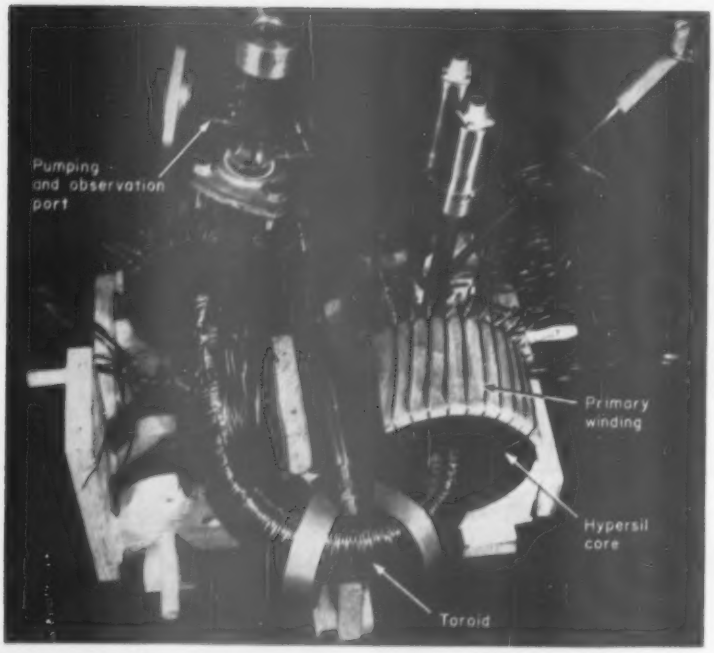

FIG. 4. The Tufts apparatus for observing the pinch effect looks more complicated than that used by Vollrath (Fig. 4) but is actually very similar. Copper wire shown circling the toroid is auxiliary winding used to provide homogeneous magnetic field in other studies

effect, which is being investigated secretly at Los Alamos (NU, Dec. '55, p. 23), has been observed by Cousins and Ware in Great Britain (*7, 8*) and is currently being studied in open laboratories at the University of Southern California and Tufts College. The Air Force has also sponsored research on high-temperature gas discharges. One expects that the much larger effort with the AEC uses methods of greater sophistication and has led to results of more direct bearing on the problem of controlled thermonuclear power. However this unclassified work gives some of the flavor of thermonuclear research.

At U. S. C. Professor Vollrath of the physics department has been doing experimental work on the pinch effect on an unclassified basis, without any AEC support or involvement. This work stems from an interest in generating high temperatures for fusion that extends back to 1936.

Vollrath's apparatus is shown in Fig. 3. With it he is able to achieve pulsed currents of 5,000 amps in hydrogen at 1-mm pressure. At these high currents the self magnetic field of the current exerts a force to pinch the current stream to smaller diameters. Vollrath observes the beginnings of this pinch in his apparatus. The gas temperatures (i.e. ion energies) involved are still far too low to hope to observe any fusion reactions.

Tufts. A group in the physics department has been investigating the behavior of gas discharges in magnetic fields under Air Force contract.* This research fits naturally into the Air Force's broad program of research, particularly because of its pertinence to processes in the upper atmosphere and possible application to high-intensity pulse light sources. Working on the project have been Prof. Lewis S. Combes (project chief), Winston H. Bostick (now on leave to Livermore laboratory), Morton Levine and Samuel Zimmerman.

Their work is completely unclassified; in particular their laboratories are open to visitors. Figure 4 shows apparatus used at Tufts to study the pinch effect.

With this apparatus, peak gas-discharge currents as high as 8,000 amps were obtained and the pinch effect observed as far back as 1952 (*10*). Highest temperatures achieved thus far are some 250,000° K, corresponding to ion energies of about 25 ev. This is obviously far too low to be significant as a fusion source. Another difficulty is that there are instabilities in the pinch effect.

Cambridge Research Center. At the Air Force's own Cambridge, Mass., research center, high-temperature gas discharges are also being investigated. Dr. Heinz Fischer is seeking high-intensity light sources.

Dr. Fischer has long been interested in researches of this type and pursued them originally in his native Germany. His approach differs from that employed at Tufts and U. S. C. Short straight-line discharges in gas at high pressure (1–50 atmospheres) are used rather than low-pressure (1 mm) toroidal discharges. By discharging special low-inductance capacitors through the gas, temperatures as high as 100,000° K have been reached. The temperature measurement is based on measuring the total instantaneous light radiation from the discharge. This is done by attenuating it by a known factor ($\sim 10^4$) and comparing with a pulsed light source of known intensity. Temperatures can then be computed from the Stefan-Boltzmann law.

Also at the Cambridge Research Center Dr. Marcus O'Day has been doing research on exploding wires with high-current pulses. Here too the maximum temperatures achieved (20,000° K) are well below those required for thermonuclear power.

* Contract AF 19(122)-89 with the Geophysical Research Directorate of the Cambridge Research Center of the ARDC.

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Zirconium—What is its Future?

Attracted by zirconium's low thermal-neutron cross section and good corrosion resistance, metallurgists have developed better alloys and improved fabrication techniques. Still needed—cheaper metal, more mechanical and corrosion data

THE PLACE OF ZIRCONIUM in reactor engineering has been put on a much firmer basis in the last few years (NU, July '53, p. 27). In spite of its several difficult properties, metallurgists have better learned how far they can extend zirconium's mechanical and corrosion limits by processing and alloying.

Evidence of the interest in zirconium is the AEC's rapidly expanding procurement program (NU, Dec. '55, p. 13). [AEC has since requested bids, due Feb. 1, for an additional 300,000 lb annually, bringing the annual AEC demand for reactor-grade zirconium to 1,200,000 lb.] It has been claimed that the Nautilus would not have been feasible without it. As an instance of its use in power reactors, the Shippingport pressurized-water reactor uses U-Zr-alloy fuel elements clad with Zircaloy-2 (NU, Sept. '55, p. 47).

Industry's confidence in the future of zirconium is indicated by the number of companies devoting facilities and money to investigating its behavior under operating conditions and to developing fabrication techniques. A number of companies were surveyed to provide the product and price tabulation on pp. 46 and 47. Fabrication methods must still be perfected to allow mass production. It can be expected that prices will drop sharply in the near future—perhaps the biggest factor will be cheaper base metal through less expensive Zr-Hf separation methods.

To assess the present status of zirconium as a reactor structural material, a conference was sponsored by the Atomic Industrial Forum in New York, November 17. This article is based on the proceedings of that conference and on a NUCLEONICS survey of commercial products available.

Zr Alloy Developments

The primary virtue of zirconium and its alloys, other than their low neutron cross sections, is their good corrosion resistance in high-temperature (<680° F) water systems, e.g., water-cooled and -moderated reactors. Zirconium-alloy systems are investigated with the aim to:

1. Develop more reproducible and predictable corrosion behavior.
2. Delay or eliminate breakaway (flaking or spalling white oxide film)—after breakaway, corrosion is faster.
3. Find alloying elements that confer corrosion resistance.
4. Utilize less expensive Kroll-process sponge.

Of the binary alloying elements, Sn,

TABLE 1—Tensile Properties of Zirconium Alloys

Alloying element (Zr base)	*0.2% offset yield strength (lb/in²)*		*Elongation in 1 in. (%)*	
	Room temp.	*500° C*	*Room temp.*	*500° C*
3% Al	55,000	28,000	30	23
3% Sn	45,000	24,000	35	40
3% Mo	73,000	30,000	~0	40
3% Nb	73,000	30,000	30	45
3% Sn-1.5% Mo	59,000	30,400	25	42
3% Sn-3.3% Al	78,900	39,400	3	6
	Yield strength (lb/in²)		*Tensile strength (lb/in²)*	
Zircaloy-2	43,000	19,000	64,000	33,000
Zircaloy-3	37,000	14,000	60,000	26,000

Reactor-Grade (Low-Hafnium) Zirconium Products

INGOTS	*Treatment*	*Size*	*Price*
Allegheny Ludlum Steel Corp.*			
Zr and Zircaloy	Conditioned ingots	800–2,200 lb; 12 or 16 in. dia.	$23/lb, f.o.b. Watervliet, N. Y.
Carborundum Metals Co., Inc.			
Zr and Zircaloy <0.015 wt% Hf	Double arc melted; machined or arc conditioned; Brinell hardness = 150	400–600 lb; min. order 500 lb	$23.07/lb, f.o.b. Akron, N. Y.
Firth Sterling, Inc.			
Zr or alloy		12 in. dia., up to 750 lb	<50 lb, $23.07/lb
National Research Corp.			
Zr and Zr-base alloys on special order	Double melted (Cu skull, consumable electrode)	Up to 25 lb	Price on request
	Arc melted, poured	Up to 50 lb	Price on request

SPONGE	*Spec's*	*Price*
Carborundum Metals Co., Inc.		
Zr <0.015 wt% Hf	Through ⅜ in. on 20 mesh; Brinell hardness = 150 max on arc-melted test ingot; max impurities <0.12%	1–74 lb, $22.00/lb; 75–600, $18.00; 600–3,000, $15.00; >3,000, $14.00; f.o.b. Akron, N. Y.

POWDER	*Spec's*	*Price*
Carborundum Metals Co., Inc.		
Zr <0.02 wt% Hf	20 mesh and finer; O_2, N_2, H_2 content higher than in sponge, other impurities similar	<75 lb, $8.35/lb; 75–500, $7.30; >500, $6.40; f.o.b. Akron, N. Y.

CHEMICALS	*Price*
Carborundum Metals Co., Inc.	
ZrO_2 <300 ppm Hf	25,000 lb, $6.10/lb; 25,000–50,000, $4.00; >50,000, $3.50; f.o.b. Akron, N. Y.
Kawecki Chemical Co.	
ZrO_2	$2.20/lb on contract basis (price dependent on contracted output of 75,000 lb of oxide per month)

FABRICATED PRODUCTS		*Spec's*	*Price*
Allegheny Ludlum Steel Corp.*(unalloyed Zr and Zircaloy)			
Forgings and rolled bar (annealed and descaled)	Slabs or sheet bars		$25/lb, f.o.b. Watervliet or Dunkirk, N. Y.
	Rounds, squares, etc. (¼–8 in.)		$31–25/lb, f.o.b. Watervliet or Dunkirk
Strip—hot rolled and/or cold rolled (annealed and descaled)	Square edge		
	Heavy-gage strip	0.157–0.187 in. thick, ⅜–4½ in. wide	$29.50–32.00/lb, f.o.b. W. Leechburg, Pa.
	Flat bar	0.188–0.300 in. thick, 2⅞–4½ in. wide	$29.50–32.00/lb, f.o.b. W. Leechburg
	Universal edge		
	Heavy-gage strip	0.157–0.187 in. thick, 3–10 in. wide	$28–30/lb, f.o.b. W. Leechburg, Pa.
	Flat bar	0.157–1.000 in. thick, 3–10 in. wide	$28–30/lb, f.o.b. W. Leechburg
	Sheared edge		
	Standard cold-rolled strip	0.156–0.005 in. thick, up to 24 in. wide	$31–47.50/lb, f.o.b. W. Leechburg, Pa.

*Fabrication and melting also done on conversion basis.

Fe, Ni, and Cr are beneficial. Although Sn decreases the corrosion resistance of pure Zr, it counteracts the effects of nitrogen in sponge. Additions of 0.1–0.5 wt% Fe, Ni, or Cr improve corrosion resistance by delaying post-breakaway corrosion in high-temperature water and steam. In ternary alloys, Fe, Ni, or Cr substantially improve the corrosion resistance of Zr-Sn.

Zircaloys

Work with Sn, Fe, Ni, and Cr led to development of the Zircaloys. These were discussed by Stanley Kass and D. E. Thomas (Westinghouse Electric Corp.), and E. T. Hayes (Bureau of Mines).

The Zircaloys are made with sponge-Zr base and Sn, Fe, Ni, and Cr added in various combinations. The compositions are—Zircaloy-1: 2½ wt% Sn; Zircaloy-2: 0.15 wt% Sn, 0.12 wt% Fe, 0.05 wt% Ni, 0.10 wt% Cr; Zircaloy-3: 0.25 wt% Sn, 0.25 wt% Fe.

Although the mechanical properties of the Zircaloys are poorer than some of the other possible structural materials (see Table 1), it is their corrosion resistance that is important for reactor application.

In building a reactor, selection of the particular Zircaloy composition depends on the particular application—it is not necessary to use Zircaloy-2 or -3. Within limits (0.1–5 wt% Sn; up to 1.1 wt% Fe, Ni, and/or Cr), corrosion resistance can be traded for strength.

The corrosion behavior of Zircaloy-1 did not come up to expectations. However, Zircaloy-2 meets the four conditions previously stated—its corrosion resistance approaches and, under some conditions, exceeds that of the purest, unalloyed Zr. Zircaloy-3 is the most recently developed member of the family. Sufficient data for complete evaluation are not yet available.

Zircaloy-2. The corrosion behavior of Zircaloy-2 is relatively insensitive to prior heat treatment and to slight variation in the concentrations of alloying elements.

The corrosion effect of nitrogen, deleterious at lower concentrations, is more pronounced as exposure time increases. After 70 days in 750° F steam, the effect is noted at 190 ppm; after 140 days, effect is observed at 120 ppm. Thus the permissible amount of nitrogen depends on the application. Similar phenomena were observed for Al and Cu; 100 ppm Pb, 50 ppm Mn,

300 ppm Be, and Co appear to have no effects.

Hydrogen is liberated during Zr-alloy corrosion by

$$Zr + 2H_2O = ZrO_2 + 2H_2$$

Zircaloy-2 picks up 10–20% of the H_2 produced in 750° F steam and 5–15% in 680° F water. Unalloyed Zr picks up 30%. Incomplete data show that the corrosion rate of Zircaloy-2 containing 4–10,000 ppm hydrogen in 750° F steam increases slightly with increasing H_2 content. Specimens containing 500–10,000 ppm hydrogen after 126 days in steam have weight gains 1½ times that for specimens containing

Company Notes

In addition to the products listed in the table, the following additional work is being done by the companies indicated:

Bridgeport Brass Co. Deep-drawn Zircaloy-2 shells are now in experimental production. Development work continues on tubing from 3-in. extruded to ⅜-in. cold-drawn. Bridgeport is cooperating with Carborundum Metals and others in a sample-preparation program; extruded billets of sponge and reactor-grade Zr and Zircaloy-2 are available. In '56, Bridgeport hopes to have moderate production of tubing in lengths up to 20 ft.

Kawecki Chemical Co. Independently of the AEC program, Kawecki has developed a Hf-Zr separation process. Although now done on a laboratory scale, facilities could be readily set up to produce large quantities of Hf-free potassium zirconium fluoride and zirconium oxide and hydroxide should the demand warrant it. The process is said to be similar to the Russian method of fractional crystallization of Zr and Hf bifluorides described at Geneva in paper 634.

Metals and Controls Corp. In fabricating fuel elements, one project is arc-melting uranium and zirconium alloys; several problems have placed Zr sponge in a minor role in this use. Metals and Controls is also working on a fuel element of uranium foil clad with Zr strip; not completely developed, it looks good for critical-assembly type of operation. A small amount of Zr scrap is being melted down for U-Zr ingots; it is an important factor in decreasing the price of fuel elements.

National Research Corp. A patented process for titanium shape-casting has been applied to Zr; vacuum casting should offer a relatively inexpensive method of producing complex shapes with high yield. Melting (up to 80-lb capacity) and heat-treating equipment are being designed and manufactured; furnaces of up to 2,000 lb Zr melting capacity (arc, skull, or cold-mold) can be furnished on order.

Nuclear Metals, Inc. Several methods have been developed for cladding fuel elements with Zr and Zr alloys. Facilities are available for testing Zr, e.g., its corrosion resistance and physical properties.

Wolverine Tube Div., Calumet & Hecla, Inc. Although now primarily concerned with tube products, Wolverine has an eye on the market for products of rolling, welding, and zirconium roll-bonded to other metals.

Reactor-Grade Zirconium Products *(Cont.)*

FABRICATED PRODUCTS	*Spec's*	*Price*
Bridgeport Brass Co. (Zr and Zircaloy)		
Extruded tubing	Up to 3.0 in. o.d., ¼–⅜ in. wall; down to 2 in. o.d., ⅛–¼-in. wall	Jobs quoted individually
Wrought tubing	1½″ in. o.d., 0.100-in. wall; down to ⅜ in. o.d., 0.020-in. wall	
Rod	As extruded or drawn down to ¾-in. round	
Chase Brass and Copper Co., Inc. (Zr and Zircaloy)		
Extruded tubing (conversion basis)	1½-in. min. i.d., 5½-in. max. o.d.; ⅛–½ in. min. wall thickness, depending on o.d.; 1-in. max. wall thickness	Price on request for specific lots
Firth Sterling, Inc.		
Sheet bar		>500 lb, $26.56/lb; <50 lb, $33.20/lb;
Forged billets	Up to 625 lb	>500 lb, $25.75/lb; <50 lb, $32.19/lb
Hot-rolled strip	0.100 mil min., 100 in. wide, 600-lb rolls	>500 lb, $28.23/lb; <50 lb, $38.18/lb
Cold-rolled strip	0.005 mil min. thickness	
Hot-rolled bars	3/16–5 in. diameter, ¼–10 in. square	>500 lb, $26.15/lb; <50 lb, $37.05/lb
Hot-rolled sheet	0.1 in. thick, 36 × 96	>500 lb, $35/lb; <50 lb, $60/lb
Cold-rolled sheet	down to 0.012 in. min. thickness	
Hot-rolled rods	⅜ in. min. diameter; cold drawn and centerless ground to ¼ in. diameter	
Wire	0.010 in. min. diameter	Price on request
Tubing	Extruded—2½–¾ in. diameter; welded—2½–½ in. diameter; both redrawn to 3/16 in. diameter and 0.020 in. wall	>500 lb, $85.00/lb; <50 lb, $110.00/lb
National Research Corp.		
Special Zr components fabricated on order; prepared to quote on shapes requiring machining and welding to close tolerance		
Nuclear Metals, Inc.		
Zr-clad fuel elements, mill products (wire, sheet, rods, tubing); sample quantities to large-scale production; prices on inquiry		
Typical sample tubing lots	½–⅜ in. o.d., 0.020–0.060 in. wall	$5–10/ft
	1 in. o.d., 0.020–0.100 in. wall	$10–30/ft
Sylvania Electric Products, Inc.		
Bid on specific items, such as fuel elements. Fabricate by powder metallurgy as well as other techniques		
Calumet and Hecla, Inc., Wolverine Tube Div. (Zr and alloys)		
Tubing		On individual order basis
Damascus Tube Co. (Zr, Zircaloy-2, Zircaloy-3)		
Welded tubing and pipe (ASTM spec's or other)	½–1 5/16 in. o.d., 0.032–0.072 wall; 1–1½ in., 0.032–0.083; 1½–2½ in., 0.042–0.083	Representative prices per 100 ft: 1-in. o.d., 18 gage—$2,018.94; 1-in. o.d., 16 gage—$2,617.96; ¾-in. o.d., 18 gage—$1,496.34; ¾-in. o.d., 16 gage—$1,929.14

4–25 ppm. Surface hydride, cathodically applied prior to corrosion testing in 750° F steam, does not appear to have any effect.

Corrosion behavior in 750° F steam at 1,500 lb/in², with or without preoxidation in dry oxygen at 750°, is analogous to behavior in dry oxygen at 750° F. Pure crystal-bar Zr is corrosion resistant to dry O_2; however, all resistance is lost in steam.

No corrosion dependence on pressure was found in 680° F water (2,705 lb/in²) or in 680° F steam at 2,500 lb/in². However, tests in 680° F steam at 1,500 lb/in² show decreased post-breakdown corrosion rate.

The microstructure of Zircaloy-2 shows inclusions, which are presumably intermetallics of Ni and Cr. Stringers also occur parallel to the rolling direction. While these do not affect mechanical properties, as measured in conventional tests, ductility is affected in operations such as shearing. Stringers maybe inert gas trapped during melting.

Zircaloy-3. Zircaloy-3 was developed to provide corrosion resistance at higher temperatures than are possible for Zircaloy-2.

Zircaloy-2 studies show that Sn-content variation of 0–1.5 wt% has negligible effect on corrosion resistance. Increasing Ni, Fe, and Cr in the range 0.20–0.35 wt% improves resistance. Fe and Ni can be substituted for one another and are more effective in imparting resistance than is Cr.

The following three alloys (in wt%) were evaluated, leading to Zircaloy-3: A—0.25 Sn, 0.25 Fe; B—0.50 Sn, 0.40 Fe; C—0.50 Sn, 0.20 Fe, 0.20 Ni. These Zircaloy-3 compositions exhibit lower post-breakdown corrosion rates than does Zircaloy-2; composition A is the lowest. Variations within 0.10% of nominal compositions have no effect. The maximum permissible impurity content (mainly N_2 and Al) appear the same as for Zircaloy-2.

That the amenability to cold-working of compositions A, B, and C is much better than that of Zircalloy-2 was brought out by R. L. Hoff (Superior Tube Co.). Thus the cost of fabricated products—tubing particularly—should be less than for Zircaloy-2.

Zr Reduction

All low-hafnium zirconium supplied for AEC and commercial reactor use is now produced by the Kroll process. W. W. Stephens (Carborundum Metals Co.) explained how $ZrCl_4$ is reduced by this method at Carborundum.

Quality-control costs amount to about two-thirds as much as all of the direct labor involved in manufacturing the product. Table 2 shows that the maximum allowable limits are for the most part 0.01% or lower. The exceptions are iron, carbon, oxygen, magnesium, and chlorine. The last two are removed almost completely when the metal is melted into ingots. These specifications are met through extremely rigid quality-control standards.

R. C. Dalzell (AEC Reactor Development Div.) commented that too much stress is placed on the mysteriousness of Zr behavior, e.g., 0.2% oxygen being damaging to mechanical properties. The standard for commercial copper is 0.03–0.05% for most products. What should be emphasized is the difficulty of keeping oxygen out of the metal, not that it is harmful.

Describing how reactor-grade zirconium specifications (Table 2) were established, Dalzell said that zirconium within these limits was found to meet requirements and that it could be produced. Thus, it was necessary to specify a great many impurities. The main goal in alloy development is to minimize zirconium's neutron cross section and then to pinpoint those impurities affecting corrosion resistance and mechanical properties. More complete data should permit less stringent specifications.

TABLE 2—Max. Sponge Impurities

Element	*Weight %*	*Element*	*Weight %*
Hf	0.01	C	0.02
Al	0.0075	N	0.01
B	0.0001	O	0.10
Cl	0.06	Li	0.0001
Cr	0.010	Rare earths	0.0015
Fe	0.10	P	0.001
Pb	0.005	W	0.005
Mg	0.060	Zn	0.01
Mn	0.005	Co	0.004
Ni	0.007	Ca	0.003
Ti	0.005	Cd	0.00005
V	0.005		

Brinell hardness = 150 for sponge arc-melted in inert atmosphere

Zr Fabrication Methods

Currently, zirconium powder metallurgy is secondary in importance to arc-melting techniques. While tubular, sheet, and bar products are generally made with the arc-melted product, powder metallurgy is used for certain special products.

Arc-Melted Products

The fabrication of zirconium from ingot to finished mill products, such as forgings, billets, bars, slabs, plate, sheet, and strip, present no problems not easily mastered by mills experienced in handling stainless, high-alloy steels, and titanium for high-temperature applications.

General considerations. In his discussion of fabrication methods, W. C. Greenleaf (Allegheny Ludlum Steel Corp.) remarked on the workability characteristics of zirconium.

The methods of fabricating Zr are about the same as for Ti. The crystal structure of these metals is similar to magnesium. They are less easily worked than iron or copper.

Zirconium has a wide hot-workability temperature range; above 400° F the tensile strength, yield strength, and hardness drop off rapidly (modulus drops only slightly); elongation rises steadily, then sharply above 750° F. Zr hot-rolls and forges satisfactorily.

Crystal structure changes from hexagonal close-packed (alpha phase) to body-centered cubic (beta phase) at 1,580° F. Quenching from above this temperature results in slight hardening. Zr can be stress-relief annealed by heat-

ing above 500° F and completely recrystallized by heating for an hour at 1,550° F.

Almost all mill products are heated and annealed in air, but very light-gage sheet and strip (also light sections of wire and tubing) anneal better in an inert atmosphere or vacuum.

Descaling Zr differs from Ti in that any tight oxide must be removed mechanically. Machinability does not differ too much from Ti.

Zirconium can be arc or flash-butt welded under inert atmosphere. Because of its reactivity with gases, the weld area must be shielded.

Powder Metallurgy

Four potential reactor uses of powder-metallurgy zirconium were pointed out by H. S. Kalish (Sylvania Electric Products): (a) special shapes for which large quantities of identical parts are required; (b) special alloys; for Zr-U alloys, better than 99% of theoretical density can be attained for all compositions up to 90% U. Zr-Be and Zr-Mg alloys have been successfully made; (c) cermets or composite materials; a mixture of Zr and BeO powders has been compacted and sintered to yield the Zr-Be eutectic structure; (d) porous parts.

The methods of fabrication can be any of five basic techniques:

1. Cold pressing and sintering. The inherent porosity can be eliminated by further fabrication.

2. Cold pressing, presintering, coining, and annealing. The item is finished by machining. This technique minimizes waste, cuts down machining costs, and provides high-density, high-purity material.

3. Hot pressing. A blank is hot pressed in a graphite die and machined to shape. This technique is suitable for lower volume production than the previous one. It saves considerable material and provides a high-density, high-purity material.

4. Powder rolling. This is suitable for making plates or rods. Once the powder is consolidated, the steel sheathing can be stripped and the usual fabrication techniques employed.

5. Powder extrusion. This method is successful with electrolytic zirconium powder because of its high ductility and relatively coarse particle size.

Electrolytic Zr powder. After the conference, J. L. Wyatt (Horizons, nc.) reported on Horizons' latest data obtained on electrolytic zirconium powder.*

Basically, the process involves the electrolysis of a fused salt bath of sodium chloride and potassium zirconium hexafluoride to produce a coarse, granular powder on a metal cathode. The product is withdrawn periodically, the deposit removed by stripping, and the salt-metal mixture purified by a simple fluosolids type of washing. Single deposits weighing up to 40 lb have been produced on a pilot-plant scale.

The majority of the material is 40–150 mesh. It is somewhat dendritic in nature, consisting of individual crystallites and tree-like agglomerates. Excellent properties are exhibited in applications involving direct extrusion from the powder and in the fabrication of component parts by powder-metallurgy techniques.†

In Nov. '55, 18 cathodes were produced in a laboratory electrolytic cell on a continuous basis. The first cathode served as a scavenger to remove impurities normally leached out of a new crucible during initial operations. A blend of the other 17 cathodes was evaluated. Vacuum-fusion analyses showed interstitial impurities of: oxygen, 0.038%; nitrogen, 0.01; hydrogen, 0.005.

Nitrogen values are probably high. Kjeldahl analyses to check this are not available, but previous batches of metal were analyzed at about 0.003%. A spectrographic analysis of a quartered sample of this composite is shown in Table 3. Hardness determinations on a 30-gm as-cast button melted on a water-cooled copper hearth showed a Brinell value of 86 under a 500-kg load. The material was too soft for the 3,000-kg-load determination on a pellet of this size.

A melted pellet with an original thickness of $\frac{5}{16}$ in. was cold-rolled and reduced in thickness 97% with no evidence of edge cracking. It exhibited considerable ductility thereafter.

Zr Looking Ahead

The growth of the demand for zirconium depends on many factors: government, industrial, and foreign programs; collection of basic metallurgical data; improved processing and fabricating methods; and, as a result of the former, price reduction. These factors were analyzed by N. C. Bartholomew (Carborundum Metals Co.).

AEC program. Including naval work, this program should have a minimum requirement of 600,000 lb in 1957. Some have estimated a far-from-conservative 2,300,000-lb demand.

Industrial power. The Atomic Industrial Forum, using 1954 as a base, predicts the nuclear power industry will be at least seven times as large in 1964 and a maximum of forty times as large. The effect will probably be something less than proportional—depending on the price of zirconium and the trend in reactor design.

Foreign programs. Current reactor designs abroad do not incorporate Zr. Presumably, other countries will follow the trend to higher temperatures and Zr. Also to be considered—urgent need for power, development of Zr production, and how U. S. production and transportation costs will affect foreign importing.

Chemical industry. U. S. corrosion losses are over $5-billion per year. This should be an important market.

Sponge utilization. Improvement in yield from sponge to end product has shown marked improvement. Fabrication on a conversion basis will end —responsibility for quality and losses will be assumed by the fabricator.

Scrap recovery. Only done on a laboratory scale now, 80% recovery will bring down prices.

Improved processing. Imminent separation and reduction developments must be given careful consideration in expansion plans.

Specification changes. Current specifications are probably more stringent than necessary. This must be verified through experience.

Price. This is a function of quantity and quality. Most of the factors listed will be determinant.

* At the present time, there is no commercial production of electrolytic zirconium. Potential users desiring small quantities should direct inquiries to C. A. Specht, Horizons Titanium Corp., Room 3418, 30 Rockefeller Plaza, New York 20, N. Y.

† H. H. Hirsch, Fabrication of zirconium by powder metallurgy techniques, *Metal Progress* **68**, No. 6, 81 (1955).

Nuclear Techniques Will Aid International Geophysical Year

Here's a glimpse of a program of world-wide geophysical research and of how nuclear techniques will be involved

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THE INTERNATIONAL GEOPHYSICAL YEAR (IGY) is actually an 18-month period, from July 1, 1957 through all of 1958, during which scientists the world over have agreed to make a well-coordinated series of measurements in order to study many natural phenomena. This IGY follows, after 25 years, the International Polar Year of the early 30's. It has been expanded to cover the entire world, and represents the first world-wide coordinated attack on the fundamental problems of the physics of our environment. It is altogether a much larger operation than the previous one and represents an effort in which perhaps one-hundred-million dollars will be spent for research the world over.

A total of fourteen different disciplines are at present involved. All these are fields in which a complete understanding necessitates a world study, for natural phenomena are no respecters of political boundaries. Such fields include among others, such world-wide studies as meteorology, aurora and airglow, oceanography, seismology, cosmic rays, ionospheric physics, solar physics, geomagnetism, glaciology, and gravity measurements. To understand these phenomena and their complex interrelations, data must be gathered from all over the world.

For example, in meteorology we do not today know whether there is a substantial and massive movement of air across the equator. As another example, we do not know much about the nature of the additional radiation that reaches us from the sun at the times of disturbances on the solar surface. We suspect that this is a charged-particle radiation, and we know qualitatively that it produces many important effects. But the details of the mechanism and the many complex interrelations have not yet been made clear. To gain an understanding we must study the phenomena as individual subjects and also as interconnected occurrences. To get an adequate picture we must make these studies on a world-wide scale, for the fragmentary knowledge available from any one nation may prove of little value or even misleading.

Some thirty-five nations have already signified their interest in taking part in this work. Naturally, the contributions of the nations will not be equal, for some nations are favorably situated to study certain phenomena. For example the zone of maximum ararural frequency passes through Alaska, Canada, and Greenland, but is too far north to pass through Germany, France, or Russia. In other countries with quite small populations such as Norway and Sweden, there happen to be specialists in certain branches who enjoy world fame as the leading persons in their fields. There will accordingly be more intensive efforts in certain fields. In addition, a number of expeditions are contemplated to cover otherwise understaffed regions. For example, important assistance from England is going to the cosmic-ray laboratory in Uganda.

Cosmic-Ray Program

An illustration of the kind of cooperative international effort which is planned for the various subjects is the cosmic-ray program. In cosmic rays, the basic problems to be studied revolve around the geophysical aspects of cosmic radiation, rather than microscopic phenomena of interest to high-energy nuclear physics.

The problems are the following: We seek

1. To record the cosmic ray intensity, in its various components, over long periods.

2. To record and then to ascertain the nature and origin of the various fluctuations in the radiation.

3. To learn about the additional radiation which comes to the earth from the sun at the time of disturbances in solar activity.

4. To learn any facts which may throw light on the puzzling problem of the origin of the radiation.

The above categories overlap one another, and it is also clear that many of these will involve studies in other IGY fields, such as solar physics, meteorology and ionospheric physics, to mention but a few.

First, to record cosmic rays over a long period, it is necessary to have, distributed over the world, a network of cosmic-ray observing stations, which will all make observations using stand-

ardized equipment, and which will all report and reduce the data in a standard manner. In order to do this, two standardized types of instruments have been agreed upon. These are, first a cubical meson telescope, and second, a neutron counter. The cubic design was decided upon, in order that everyone would have the same angle of aperture, and could build as large or small an instrument as his budget would allow. Thus all cubes will use the same meteorological corrections, and will look out into space through the same solid angle. Radiosonde meteorological data is required, as one of the corrections which is to be made to the data is a coefficient involving the height of the 100-millibar layer. The telescope involves 10 cm of lead between the layers of counters, and thus measures the hard component of the radiation.

To record the soft component, a standardized neutron monitor has been agreed upon. This consists of a set of neutron counters inside a paraffin moderator, together with a necessary electronic recording equipment. Several of these monitors are already in operation, and others are to be built and installed. Altogether it is hoped to have a network of these and the cubical meson telescopes distributed over the world both in latitude and longitude. Those distributed in a latitude will give us information about the energy spectrum of the incoming radiation, while those at the same latitude but different longitudes will tell us about the times of arrival of radiation in various impact zones. Thus it will be possible to see whether we can follow a given impact zone around the earth and thus deduce whether the cone in which the radiation is emitted from the sun is large or small. Another important factor to be studied is the long-period constancy of the radiation, for upon this depends the evaluation of long-term terrestrial cosmic-ray effects such as radiocarbon dating, of great importance in archaeology.

In addition, such other equipment as is now in operation will continue. This includes the well known network of Carnegie ionization meters, which have now been giving an excellent summary for nearly twenty years. Narrow-angle telescopes will also be used. These are not standardized in angle, for different angles are required for differing specific problems in certain latitudes. Other telescopes deep under the ground have been proposed and will be used.

Satellites. A part of this program is the earth satellite. This vehicle will carry cosmic-ray counters. If the plan proposed by the cosmic-ray group is put into effect, the satellite will describe pole-to-pole orbits, thus sweeping out a latitude range each time it circles the earth. Since the earth will rotate under the plane of its orbit, it is hoped that a comprehensive map of the incoming cosmic radiation will be obtained, both in latitude and longitude. Analysis of this map, with the aid of the geomagnetic theory of the motion of charged particles in magnetic fields will give the incoming primary spectrum in energy, and possibly by subsidiary measurements, in particle types as well.

In addition to this program of observations with standardized instruments, which are thus on a world-wide intercomparable basis, there will also be a set of observations designed to throw light on one or more special problems, for which only a few observations are required. For example, there are many problems that can be solved by a small number of balloon flights carrying specially designed equipment to high elevations. In the majority of cases there is no need to repeat the series, after the initial flights have answered to the question. In some cases the problem can be solved by making simultaneous flights at several separate latitudes. For example, much light is thrown on the energy spectrum of the incoming radiation if it is possible to have simultaneous flights at three or four different latitudes not differing too far in longitude. Such a set has for example been discussed for stations at Thule (Greenland), New York, and Puerto Rico; or at Churchill, (Manitoba, Canada), Texas, Panama and Peru; or from Fairbanks Alaska and Hawaii, to give data along the 160th meridian of longitude. For these observations, the most important feature as far at the IGY is concerned is prompt publication. Hence at each international meeting, publication has been stressed, and it has been agreed that all observers will make every effort to publish as quickly as possible.

All over the world observations are being simultaneously contemplated in a number of interconnected disciplines; a central clearing house is being set up for the data; standardized equipment is being used so that the observations will be intercomparable, and the measurements are being made at agreed-upon times and places. Solar flares and other disturbances will be specially patrolled, and warnings sent over a communications network. Special World Days are designated for certain types of observations in advance, others will follow warnings at stated intervals. In this manner it is hoped that a vast amount of new and useful data will be accumulated.

World-Wide Tracer Studies for IGY

The distribution of isotopes produced by the cosmic radiation will be intensively studied in the International Geophysical Year. For example, carbon-14, the new and immensely valuable dating tool, will be used in studies of the ocean floor. Also, although (as Libby has shown) the isotope itself is well mixed because of its long half life, there is a large altitude and latitude effect in the rate of production of the cosmic ray neutrons and hence in that of the radiocarbon itself. This study will be in the IGY program.

The world distribution of tritium will also be studied. Since in this case the half-life is much shorter, it appears probable that many new and interesting variations in the world distribution will be found. Indeed it is hoped that tritium will in due course prove to be a good short-time dating tool, as useful as radiocarbon but probably in quite a different set of studies. There is a great deal which we do not know today about the distribution of tritium. It may be possible to use tritium to study the movement of ocean waters or possible glaciers. Contamination with man-made tritium from bomb tests is a problem, its extent being only vaguely known. We do not know whether there is any in the Southern hemisphere.

Conceivably expanded and integrated measurements of fallout from any nuclear weapons tests during the IGY could lead to better understanding of atmospheric dynamics and shed light on the question of how extensively the air of the Northern and Southern hemispheres is exchanged.

CRISIS: Nuclear Education

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the peaceful atomic energy industry. And always looming in the background is the spectre of the high-pressure scientific training program in Russia, where 31% of 1954 graduates were engineers, as against less than 8% in the U. S. Total figures are even more disturbing: in 1954 Russia graduated 53,000 engineers and scientists, the U. S. 23,000.

The educational crisis is not only one of quantity but of quality, Admiral H. G. Rickover said recently. "I submit that the present-day pupil is not adequately trained," he asserted. "All but a small number of young college graduates lack proper motivation. . . . (Also) they know many facts but have not learned many principles."

Opportunities Available

NUCLEONICS presents below a rapid review of nuclear educational opportunities available in the U. S. today.

Governmental—Most advanced instruction is to be found in the national laboratories, because here are located both the big, costly machinery needed by the new science, and the men who built and can operate it. Two such schools exist.

The Oak Ridge School of Reactor Technology (ORSORT), founded in 1950, gives a 12-month course including classified information for 80 U. S. citizens having Q clearance. Applicants must be sponsored by the AEC or one of its contractors, or another government agency or branch of service or their contractors, or an industrial firm with an active interest in reactor development. Tuition, payable by the last category only, is $2500. Deadline for applying for the 1956–57 session is March 12.

The School of Nuclear Science and Engineering (SNSE) at Argonne, founded in 1955 as part of the Atoms-for-Peace program, presents only unclassified material; 30 of 39 students in the first 7-month course completed in October, and 45 of 66 in the second course begun in November, are foreign. As one of the aims of SNSE is to promote friendship between countries, the atmosphere is deliberately not competitive; students are not graded. Foreign students must be sponsored by their governments, Americans by their own companies. Tuition is $1500. Work is on three levels: for holders of bachelor's degrees, of master's degrees, and more advanced students. It is planned to increase enrollment to 120 in 1957; 250 in 1958; 500 in 1959.

AEC makes available number of fellowships for a year of formal study in industrial hygiene at Harvard or Pittsburgh University, and in radiological physics at Rochester U. and Brookhaven National Laboratory; at Vanderbilt U. and Oak Ridge National Laboratory; or at Washington U. and Hanford.

AEC also offers on-the-job training at the national laboratories for experienced engineers and scientists. Industrial firms and governmental agencies contract to have one or more of their Q-cleared employees trained, usually for one year. The trainee is assigned to a research or development project most closely fitting his needs, and works as an active participating member of a lab team; he contributes his skill and industrial experience, and acquires the know-how and technology unique to nuclear energy utilization. At present there are about 200 such trainees, from 90 organizations.

Finally, some of the national laboratories offer special part-time courses given by staff men or faculty members of nearby universities. For example Argonne recently gave courses in reactor engineering, computer programming, radiation biology, scientific Russian, heavy-metal chemistry and accelerator problems.

University—According to one recent estimate, about 175 of the 1000 accredited U. S. colleges and universities offer some form of nuclear instruction —such as modern physics, or radiochemistry, or safe handling of radioisotopes. Less than 50, however, offer a real graduate program in reactor science and engineering. Another survey shows that North Carolina State and Iowa State offer nine courses in nuclear engineering; MIT 8; the U. S. Naval Postgraduate School at Monterey, Calif., 5; Columbia, Michigan and Tennessee 4, and some 30 more list one to three courses.

North Carolina State, Penn State, Michigan, California and MIT have built or are building research reactors for student training; MIT, in addition, has maintained an engineering practice school at Oak Ridge since 1948.

Candidates for masters and doctoral degrees can get AEC aid in the form of university research contracts.

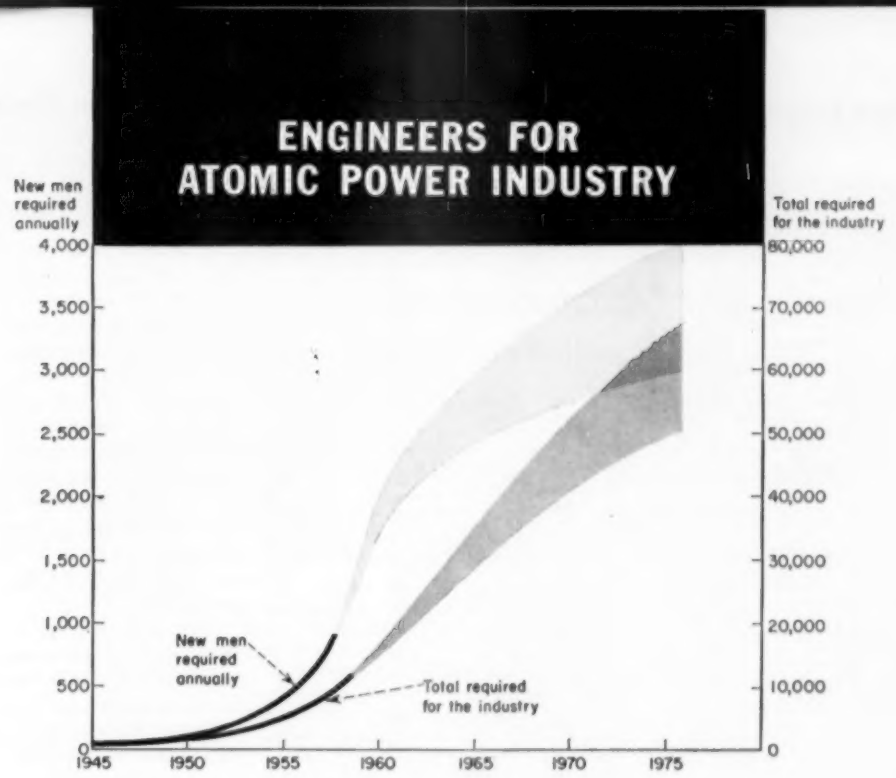
Joint Programs—Two leading nuclear equipment manufacturers are collaborating with universities. A unique program is the joint fellowship scheme in reactor engineering and physics offered by Westinghouse and Pittsburgh University. This four-year combination of on-the-job training and formal courses permits fellows to earn a regular industry-scale salary while earning a Ph.D. in reactor engineering or physics. At Hanford, General Electric in cooperation with the Universities of Idaho and Washington and the State Colleges of Washington and Oregon is offering 37 graduate courses, four of them in reactor technology.

Short-term or part-time courses—The number of specialized short courses is increasing. For example, in the New York area, NYU's Postgraduate Medical School and College of Engineering together with AEC are giving an introductory course on radiological safety; two time schedules are offered: full-time daily for two weeks, or one afternoon a week for 17 weeks. And Queens General Hospital, also in cooperation with AEC, has a four-month course in the medical uses of radioactive isotopes.

The Oak Ridge Institute of Nuclear Studies (ORINS), founded in 1947 by 32 southern universities, specializes in four-week courses in basic radioisotope techniques. It also gives advanced two-week courses in radiological and health physics, veterinary radiological health, and the use of radioisotopes in hematological studies.

The Atomic Industrial Form has entered the teaching field with a two-week course on reactor materials for 60 senior chemists, engineers and metallurgists. The National Industrial Conference Board has developed a one-week familiarization course for business executives without scientific training.

Another type of education, company-organized spare-time courses for employees, is typified by the elementary nuclear physics course at General Dynamics' Electric Boat Division shipyard. The demand for this course of six 1½-hour lectures given after working hours to engineers, draftsmen,



technicians, supervisors, clerical help and even some wives of employees has been so heavy that it is being given continuously and promises to run indefinitely.

Labor unions are also getting into the picture: both the Boilermakers and the Plumbers & Pipefitters have training programs under way.

Teacher training—AEC has for some time been conducting retraining or refresher courses at its laboratories for university faculty members, who work on research and development projects as regular employees either during summer vacations or sabbatical leaves. Regional conferences and short-term study courses are also sponsored. About 250 faculty members are participating in these programs today. In addition AEC announced in December establishment of an eight-week summer institute at SNSE for 60 university engineering teachers. Sponsored by AEC, the National Science Foundation, the American Society for Engineering Education and Northwestern University, the institute is to equip more engineering faculty members to teach nuclear science.

ORINS will also hold two one-month institutes for science teachers this summer, one for secondary school, one for college-level teachers.

AEC has resigned itself to carrying the major burden of training or retraining college instructors in nuclear technology, for the next five years at least, in its own laboratories.

The Six Megabuck Program

As this goes to press, AEC is readying for presentation to Congress an expanded program of aid to education. It calls for an outlay in fiscal '57 of $6-million which would include both fellowship aid for formal study at universities having nuclear engineering courses, and aid to universities in acquiring capital facilities such as exponential reactors, instruments, heat transfer loops. These funds must also cover cost of supplying and fabricating fuel for exponential piles such as NYU's pickle-barrel reactor, as well as meeting ORSORT and SNSE operating expenses. If Congress appears willing to go along, AEC will continue this type of aid regularly; but it is treading warily because "we don't want to get in the middle of (the controversy over) Federal aid to education." Also AEC is aware that money alone cannot solve the problem, what with the bottleneck in teaching staff.

What Else Should Be Done

In a pungent speech before the Thomas Alva Edison Foundation, Admiral Rickover made some concrete recommendations on meeting the crisis.

- Increase the funds for education ("we spend 2½% of the national income on education, more than 4% on recreation.")
- Tackle the present shortage of 140,000 qualified teachers by paying higher salaries to attract more and higher-caliber people.
- Increase the length of the school year ("Industry cannot operate effectively on a 180-day year; why should we think our schools can? . . . A 210-day school year would be the equivalent of making two additional years available before college.")
- Set up two kinds of high schools, one having higher standards ("True democracy does not require that we hold back the qualified; it does require that we give each individual the opportunity to develop his talents to the fullest.")
- Industrial firms should "at their own expense make available their scientists and engineers for one-year periods to teach in our high schools, colleges and universities."
- Industry can also make financial contributions to education—rather than scholarships and "on a considerably larger scale" than is done at present—"perhaps as a percentage of gross sales, as a legitimate operating expense required for the future good of the business."

CROSS SECTIONS

Voltage Calibration System for Pulse-Height Measurement

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Iowa State College
Ames, Iowa

Accurate calibration or linearity measurements of electronic equipment are needed in experimental nuclear research. This is especially true when electronic equipment must be used to amplify or treat voltage pulses that are varying in amplitude, and the relative amplitudes must be preserved. The accuracy of experimental results of this type is affected by the accuracy to which the linearity of the electronic equipment used can be determined. This includes equipment such as cathode followers, amplifiers, attenuators and pulse-height analyzers, etc.

The system described here was devised to provide a convenient and accurate means of determining linearities or non-linearities of pulse equipment and of obtaining data for plotting calibration curves of the equipment used.

Methods commonly used for measuring pulse amplitudes are peak-reading voltmeters, square-wave voltage calibrators in conjunction with an oscilloscope, bridge circuits for comparing pulse energies with a d-c voltage, and comparison of so-called standard pulses with unknown pulses by means of an oscilloscope. The accuracies obtainable by these methods are usually limited to 2 or 3% at best and the systems are not versatile in terms of pulse-height range, pulse shapes or pulse polarities.

A desirable system would seem to be one in which a pulse height can be measured by comparison to a d-c voltage. Very accurate and stable sources of d-c voltage are readily available, and it is easy to attenuate and control such a voltage accurately. It is also desirable to use a visual-comparison method so that measurements can be made on that portion of the pulse that is of interest.

The system described incorporates these features while at the same time eliminating or reducing errors such as those described in other systems above.

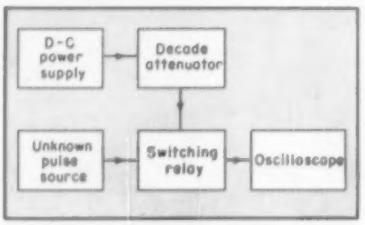


FIG. 1. Voltage calibration system. Oscilloscope amplifier must be d-c amplifier with upper-frequency response limit high enough to avoid distortion of height of measured pulses, and should be capable of output sufficient to deflect crt beam 6 in. or more vertically. Vertical positioning control needs suitable range to display top of pulse on screen. DuMont type-329 oscilloscope is used in present system. Single-pole double-throw switching relay used is operated from 60-cycle line to connect output of d-c attenuator and source of unknown pulse voltage alternately to oscilloscope input

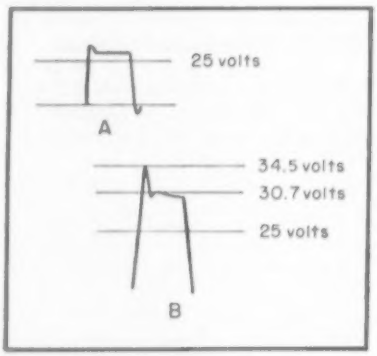


FIG. 2. Procedure for pulse measurement is indicated by photographs of oscilloscope screen. *A* is positive pulse about 1 μsec wide displayed with normal amplification. In *B* amplifier gain has been increased and positioning control adjusted to display portion of interest. *B* is superposition of three positions of d-c calibrating line

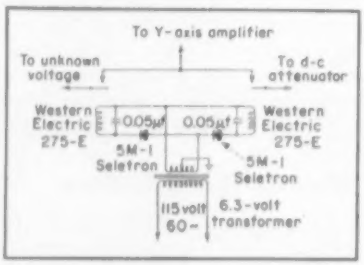


FIG. 3. Switching relay circuit for very small pulses

General Description

A block diagram of the system is shown in Fig. 1. This system will produce on the oscilloscope screen a display of the unknown pulse alternating with the d-c calibrating voltage. Due to the 60-cycle switching rate and the persistence of the cathode-ray tube phosphor, a superimposed image of the two signals can be viewed. By adjusting the decade attenuator, the position of the d-c line is adjusted to coincide with the portion of the pulse to be measured. Any error due to parallax is eliminated by this method of comparison.

The pulse height in volts can be determined by measuring the d-c voltage from the decade attenuator. If a precision attenuator is used, the voltage may be read directly from the attenuator dial settings. Because of the expansion feature of the vertical deflection amplifier as noted in Fig. 1, this matching can be done with an accuracy limited by the width of the oscilloscope trace in comparison to the total deflection of the unknown pulse. With the equipment described this is approximately 0.1%.

The procedure followed is demonstrated by photographs of the cathode-ray tube screen in Fig. 2. For pulses of negative polarity the same procedure is followed, only a negative d-c voltage is used. The unknown pulse is used to synchronize the sweep of the oscilloscope so that a stable pattern is presented for viewing.

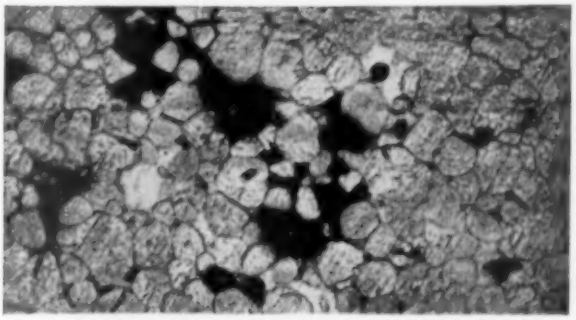
Circuitry

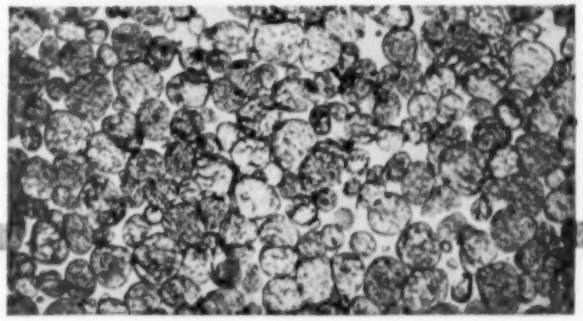
The d-c power supply used can be any power supply capable of delivering 200 to 250 v at 80 to 100 ma with good regulation. The power supply used here has a regulation of 0.05% or better and long-time stability of better than 0.1%.* However, any good commercial power supply with the desired specifications could be used. The supply should be able to deliver either a positive or negative voltage with respect to ground depending upon which output terminal is grounded by the operator. The voltage need not be variable.

The decade attentuator circuit uses

* Circuit diagrams for power supply and decade attenuator are given in ISC-598 (1955), upon which this article is based.

MALLORY





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three rotary switches of the 10-position, 2-circuit type in addition to a 10-turn Helipot for adjusting the output voltage. A full-scale range selector switch determines the polarity of the output voltage and selects either 100 or 200 volts to be applied to the attenuator section. On the 100-volt ranges the output voltage of the attenuator can be read directly from the dial settings of the attenuator. On the 200-volt ranges the dial reading is multiplied by two to obtain the output voltage. The attenuator can be set from zero to 99.9999 in increments of 0.0001 corresponding to the smallest division on the Helipot dial.

Resistors used in the attenuator are selected by bridge measurement to approximately 0.05% of listed values and are rechecked after being soldered in the circuit. In this case wire-wound IRC BW-type resistors were used. Any low-temperature coefficient resistor could be used, however.

The full-scale adjusting potentiometers are adjusted to deliver exactly 100 and 200 volts, respectively, to the attenuator. These should be adjusted with power applied and after a reasonable warmup period. The impedance of the attenuator must be kept low so that the 2.2-megohm input impedance of the oscilloscope does not seriously load the attenuator.

A sigma-type 4F-100S-Sil relay may be used as a switching relay in applications where the minimum voltage to be measured is 0.1–0.2 volts. The relay is driven by a 6.3-volt filament transformer connected to the 60-cycle a-c line; a half-wave selenium rectifier is used in the relay coil circuit so that the repetition rate is 60 cycles per second rather than 120.

An alternate circuit for switching is shown in Fig. 3, and is useful for measuring lower voltages where contact bounce and arcing might result in pickup and jitter in the oscilloscope pattern. Two mercury relays are required for this application so that the bridging effect of the mercury contacts can be eliminated.

Pulse leads should be kept reasonably short to prevent capacitive loading of the pulse source. Where possible, measurements should be made at low impedance points in a circuit under test so that the added capacity of the leads will not introduce pulse distortion.

Reducing Inaccuracies

The possible sources of inaccuracy in determining pulse heights by this method and steps taken to reduce or eliminate them are:

1. **Instability of the power supply voltage.** This is not a serious source of inaccuracy to the system as regulated power supplies are available with accuracies approaching a standard cell.

2. **Inaccuracies of resistors used in the decade attenuator.** These can be reduced by selecting resistors by bridge measurement to the required degree of accuracy and by using resistors of low temperature coefficient. This error can be eliminated completely if the output voltage from the d-c attenuator is actually measured by an accurate potentiometer rather than reading the voltage from the dial settings. This is more time-consuming and not as convenient as using a direct reading. The accuracies obtainable by careful construction of the attenuator are usually suitable.

3. **The input attenuator of the oscilloscope amplifier.** This is a step-type attenuator and can be accurately compensated capacitively so that negligible errors are introduced in attenuation ratios for the d-c voltage in comparison to pulse voltages.

4. **The vernier gain control of the oscilloscope amplifier.** This is a very low-impedance potentiometer used as an attenuator between stages two and three of the amplifier. Because of its low value, capacitance effects are negligible for pulses in the frequency range of the amplifier.

5. **Frequency response of the amplifier.** It is necessary that the upper frequency response limit of the amplifier be high enough to reproduce the pulse with negligible distortion in amplitude. The 10-megacycle response of the amplifier used is sufficient for pulses of a fraction of a microsecond in width. It is also necessary that the d-c gain of the amplifier be the same as the gain at frequencies of primary interest in the unknown pulse. In other words the response curve of the amplifier should be reasonably flat from d-c to its upper frequency limit. This requirement is met very well by the amplifier used.

Linearity and drift of the amplifier are of no importance since both the calibration and the unknown signals are treated the same. Consideration of all the above factors places a limit of 0.2–0.3% on the accuracy of the present system.

The minimum signal for which the system is useful is determined by the maximum gain of the oscilloscope amplifier and is approximately 0.1 volt for the DuMont type-329 oscilloscope. A suitable d-c preamplifier can be used ahead of the oscilloscope amplifier however, and the range extended down to a few millivolts. The maximum signal with which the calibrator has been used is 200 volts.

The amplitudes of pulses with widths as low as a fraction of a microsecond and as high as several thousand microseconds and of either polarity can be measured. Repetition rates below a few hundred cycles per second should be avoided to prevent synchronizing difficulties due to the 60-cycle switching rate. Pulse widths longer than a few thousand microseconds should also be avoided as the pulse width becomes an appreciable part of the switching period. This makes it difficult to obtain a good display for matching purposes on the oscilloscope.

Unknown d-c voltages can be measured very conveniently by using a fast oscilloscope sweep and matching the d-c lines, using the same procedure followed for pulses.

* * *

The authors wish to acknowledge the assistance of J. E. Griffin of this laboratory in the development of this system.

Determination of Zr^{95} in Fission Product Mixtures

By RICHARD B. HAHN
and RICHARD F. SKONIECZNY
Chemistry Department
Wayne University
Detroit, Michigan

The barium fluozirconate method (*1*) is commonly used for determining radioactive zirconium (Zr^{95}) in fission products. In this procedure zirconium is separated from other activities by precipitation as insoluble barium fluozirconate, followed by a final precipita-

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TABLE 1—Effect of Carrier Weight on Self-Absorption of Beta Activity

Zirconium carrier (mg)	*Zirconium tetramandelate (mg)*	*Zirconium yield (%)*	*Activity* (cpm/ml)*
4.68	22.4	62.67	3.27×10^5
4.68	21.1	59.04	3.43×10^5
9.36	43.2	60.53	2.68×10^5
9.36	37.2	52.12	2.75×10^5
18.72	96.2	67.41	1.60×10^5
18.72	96.3	67.48	1.59×10^5

* 3.50×10^5 cpm of Zr activity added to each sample.

tion with cupferron. This is ignited to zirconium dioxide, which is then weighed and counted.

This method gives excellent separations from other activities. The only disadvantage lies in the use of cupferron. Cupferron (*2*) (the ammonium salt of nitroso phenyl hydroxylamine) is unstable in water, hence solutions must be prepared freshly before use, or must be stored under refrigeration. The cupferron-zirconium precipitate is bulky and spatters badly upon ignition. Because of these disadvantages, other reagents were considered. Mandelic acid and its derivatives seemed most promising.

Kumins (*3*) showed that mandelic acid was a specific precipitant for zirconium. He devised a procedure for determining zirconium in the presence of various interfering elements. Astanina and Ostroumov (*4*) found that under controlled conditions, the zirconium mandelate precipitate could be weighed directly without ignition to the oxide. Zirconium tetramandelate is a dense, crystalline precipitate that is easily filtered and washed. It can be readily mounted and counted in radiometric analysis.

Modified Procedure

By substituting mandelic acid for cupferron, the following modification of Hume's barium fluozirconate procedure was devised. The first five steps are essentially the same as those given by Hume, with the exception that the volume and weights of reagents are only about one-fourth as large. This modification was necessary to minimize self-absorption of the beta particles by the final precipitate of zirconium tetramandelate. Five milligrams of zirconium carrier gave optimum results. (See Table 1.)

The procedure is as follows:

1. Add 5 mg of zirconium carrier (in zirconyl nitrate solution) to 1 ml of 6*N* nitric acid in a Lusteroid centrifuge tube. Add a known amount of the radioactive solution to be analyzed, 0.5 ml of 27*N* (conc.) hydrofluoric acid and mix thoroughly.

2. Add 0.25 ml of lanthanum nitrate solution (10 mg La^{3+}/ml), stir thoroughly, centrifuge, add a second 0.25 ml of lanthanum nitrate carrier, and centrifuge the precipitate down on top of the first precipitate. Decant the supernate to a clean Lusteroid tube and discard the precipitate.

3. Add 1 ml of barium nitrate carrier solution. Stir thoroughly, centrifuge, and discard the supernate.

4. Suspend the precipitate in 2 ml water, add 1 ml of saturated boric acid solution, dissolve by adding 0.25 ml of 15*N* (conc.) nitric acid and stirring until a clear solution is obtained. Add 0.5 ml of barium nitrate carrier solution and 0.25 ml of conc. hydrofluoric acid to the clear solution. Stir, then centrifuge down the precipitate and discard the supernate.

5. Repeat step 4.

6. Suspend the precipitate in 2 ml of water and 0.5 ml of boric acid. Dissolve by adding 2 ml of 6*N* hydrochloric acid. Add 6*N* sodium hydroxide while stirring to the above solution until it is basic. Centrifuge and discard the supernate.

7. Dissolve the precipitate of zirconium hydroxide by adding 3 ml of 12*N* (conc.) hydrochloric acid and 3 ml of water. Transfer this solution to a glass centrifuge tube. Rinse the Lusteroid tube twice with 1-ml portions of water and add these washings to the solution in the glass tube. Add 10 ml of saturated (15%) mandelic acid solution. Stir and heat in a water bath at 80°–90° C for about 20 min.

8. Filter the hot solution using weighed 1-cm filter paper disks in a Hirsch funnel. Wash with 10 ml of 5% mandelic acid-2% hydrochloric acid mixture, then with three 5-ml portions of 95% ethyl alcohol and finally with two 5-ml portions of ethyl ether. Transfer the precipitate and filter paper to a tared watch glass and dry under a heat lamp for about 5 min. Weigh, then mount for counting.

TABLE 2—Zr^{95} Determination by Cupferron and Mandelic Acid Methods (Beta Count*)

Sample	*Cupferron (cpm)*	*Mandelic acid (cpm)*
1	699	748
	772	761
2	791	766
	788	779
3	3.63×10^5	3.50×10^5
		3.87×10^5
4	2.74×10^5	2.61×10^5
	2.73×10^5	2.71×10^5
5	2.40×10^5	2.39×10^5
	2.44×10^5	2.40×10^5

* Accuracy is ±3%.

TABLE 3—Zr^{95} Determination by Cupferron and Mandelic Acid Methods (Gamma Count)

Sample	*Cupferron (cpm)*	*Mandelic acid (cpm)*
1	8,432	7,327
	8,296	7,385
2	7,641	6,900
	7,517	6,625
3	8,609	7,829
	8,332	7,782
4	7,671	7,119
	7,532	6,703

Reagents

Zirconyl nitrate, lanthanum nitrate, barium nitrate, and boric acid are prepared as in Hume's procedure (*1*). Mandelic acid (saturated): 160 gm of solid mandelic acid dissolved in 1 liter of water.

5% mandelic acid-2% hydrochloric acid wash solution: 50 gm of solid mandelic acid and 48.5 ml of concentrated hydrochloric acid (37%) are dissolved in enough distilled water to make 1 liter of solution.

Sodium hydroxide (6*N*): 240 gm of

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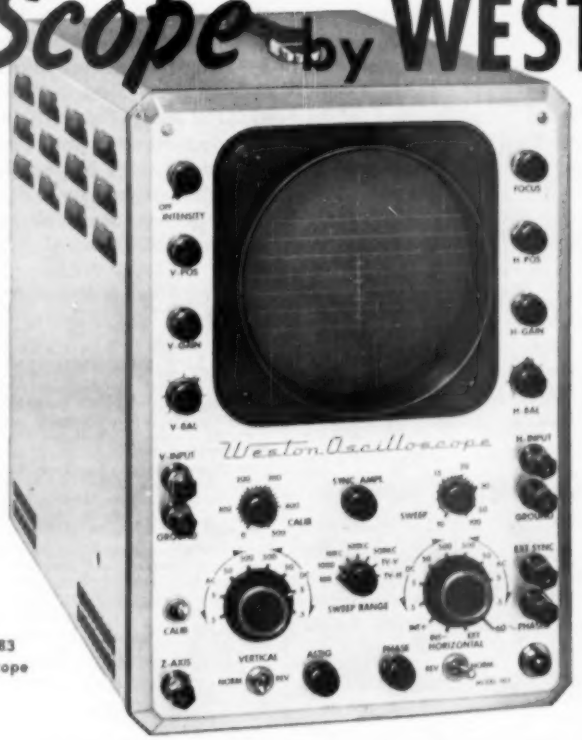

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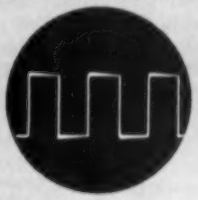

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solid NaOH dissolved in distilled water to make 1 liter of solution.

Discussion

The procedure was tested by analyzing identical samples of zirconium-niobium tracer by Hume's cupferron method and by the mandelic acid method given previously. A mica end-window (2.3 mg/cm²) G-M tube and scaler were used for beta counting.

The data in Table 2 show the mandelic acid method gives results comparable to those obtained in the cupferron method.

A second series of samples were run in which the gamma activity was counted (see Table 3). A bismuth-wall G-M tube and scaler were used.

The gamma counts obtained by the mandelic acid method were 6–14% lower than those obtained by the cupferron method. No suitable explanation can be offered for this discrepancy. The mandelic acid method, therefore, is not recommended for analyses made by gamma counting.

Separation from F.P. Activities

To study the effectiveness of separation of zirconium activity from other fission products, the mandelic acid procedure was repeated with samples containing approximately 10^4 beta counts per minute of Ce^{144}-Pr^{144}, Nb^{95}, and Sr^{90}-Y^{90}. In all cases less than 100 cpm was obtained. Thus the method can be used for determining zirconium in the presence of these activities.

p-Bromomandelic Acid

Experiments were conducted using *p*-bromomandelic acid (*5*) in place of mandelic acid. The precipitates of zirconium tetra-*p*-bromomandelate were much larger in weight and in volume than those obtained with mandelic acid. The analytical results were poor owing to self-absorption of the beta particles by the precipitate. Since this reagent has no particular advantage over mandelic acid, it is not recommended.

* * *

This work was supported in part by a grant (AT-11-1)213 from the Atomic Energy Commission.

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Durable White Coating Improves Liquid Scintillation Counters

By D. E. BANNERMAN and R. J. LANTER
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

We have used large (20-liter capacity) liquid scintillation counter tanks for several years and have found deep-drawn aluminum tanks with welded tops and etched inner surfaces to be satisfactory. These counters are used to detect 14-Mev neutrons (*1*), 2-Mev neutrons, and various gamma rays. Our liquid consists of 5 gm of terphenyl per liter of toluene with 0.01 gm of 2-(1-naphthyl)-5-phenyloxazole (alpha-NPO) per liter of toluene as a wave-shifter (*2*).

We tried various wall coatings to improve counter sensitivity (amplitude of integrated photomultiplier output voltage due to radiation burst at standard source-counter distance).

Among the coatings we tried were white Tygon paint (*3*), magnesium dioxide in lacquer (*4*), alumina in lacquer, titanium dioxide in waterglass, and titanium dioxide in lacquer. The last resulted in the greatest sensitivity, but it peeled from the aluminum wall as the lacquer dried. We then developed a method to produce a durable coating of titanium dioxide in lacquer.

Application of Coating

The method of applying the coating is as follows:

1. Etch tank in 10% sodium hydroxide solution at 160° F for 1 min; rinse.
2. Immerse tank in a solution of one part concentrated nitric acid to three parts of water until a bright matte finish appears (about 1 min).

3. Rinse in distilled water; allow to dry (if discoloration is still present in tank, repeat first two steps).

4. Rinse tank with toluene and allow to dry (a blower may be used, but do not use a compressor-type air supply in any steps because of oil in the air).

5. Pour into tank a solution of 1.5 parts of Zapon Aquanite clear lacquer thinned with 1 part Aquanite lacquer thinner (Atlas Powder Co.); turn tank until all surfaces are covered; pour out excess; drain for 4 hr; then blow in air for 12–16 hr.

6. Mix 2 pints Zapon Aquanite clear lacquer with 1 pint Aquanite lacquer thinner and 1 lb titanium dioxide (TiO_2) (reagent-grade powder, J. T. Baker Co.); stir with motor stirrer for 4 hr to achieve good blending.

7. Pour mixture into tank; turn tank to coat all surfaces; pour out excess; drain for 1 hr.

8. Dry for 16 hr in air without blower, dry for 8 more hr with blower.

We found that thin coats are essential for good adherance. Due to the thinness of the coating, a second coat of the TiO_2 mixture, steps 7 and 8, will increase the counter sensitivity. A third coat does not help appreciably.

Improvement with Coating

We measured relative sensitivities of etched and coated counters using short bursts of 14-Mev neutrons. The average values found were:

Type tank	*Relative sensitivity*
Etched	1.00
Single coat, TiO_2	1.50
Double coat, TiO_2	1.70

This coating has been found to be extremely tough, surviving cutting of the surface and other rough usage. It has withstood over 6 months contact with toluene without peeling.

This procedure also has been used to coat containers for various size plastic counters. The gain in sensitivity of plastic counters by the coated surface over the etched surface is about the same as for the liquid counter.

* * *

This work was performed under the auspices of the United States Atomic Energy Commission.

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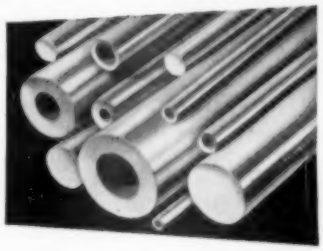

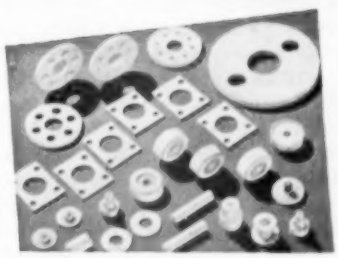

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Production of P^{33} by Neutron Irradiation of Sulfur

By INGRID FOGELSTRÖM and TORBJÖRN WESTERMARK
Division of Physical Chemistry, Royal Institute of Technology, Stockholm, Sweden

Lately, workers in biochemistry and medicine have taken a great interest in obtaining P^{33} for the double-labeling of phosphorus in metabolic organic compounds. Pure P^{33} is also wanted so that its nuclear data can be determined more accurately.

Reactor Production

Until now there has been no regular production of P^{33}, which may be due to the great difficulties in obtaining pure P^{33}. It can be produced in a nuclear reactor from sulfur by the reaction $S^{33}(n,p)P^{33}$. However, ordinary sulfur only contains 0.75% of S^{33}, the rest being mainly S^{32}, which yields P^{32} by the reaction $S^{32}(n,p)P^{32}$. Since the cross-section for fast neutrons is about the same for both reactions, the active phosphorus produced will contain only about 1% P^{33}, the rest being P^{32}.

There are, however, two differences between the isotopes and their formations that might be used for the production of P^{33}. P^{32} is produced by an exothermic reaction, the Q-value for this reaction being +0.52 Mev, while the corresponding value for P^{32} is −0.93 Mev. P^{33} is thus produced by an endothermic reaction. The other difference between the isotopes is the half-life, being 25 days for P^{33} and 14.3 days for P^{32}. Owing to these differences there are two ways of producing reasonably pure P^{33} by the neutron irradiation of sulfur, i.e., either by using neutrons of an energy below the threshold energy for P^{32} formation, e.g., thermal neutrons, or by aging sulfur irradiated with fast neutrons.

In a reactor, the fast flux decreases much more rapidly in the reflector and in the thermal column than does the thermal flux. Therefore, if one irradiates sulfur in these places, one ought to get a larger amount of P^{33}, compared to P^{32}, than in the center of the pile. Thus, in 1952, T. Westermark (*1*) obtained a P-activity with about 30% P^{33} by irradiation of sulfur near the reflector of the Harwell reactor.

To investigate the percentage of P^{33} in the total P-activity obtained in different places in a reactor, irradiations

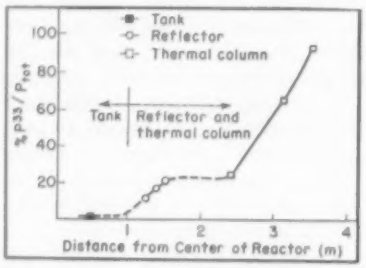

FIG. 1. Per cent P^{33} formed varies with distance from center of Norwegian D_2O reactor. Circles are experiments by Nilsson (2)

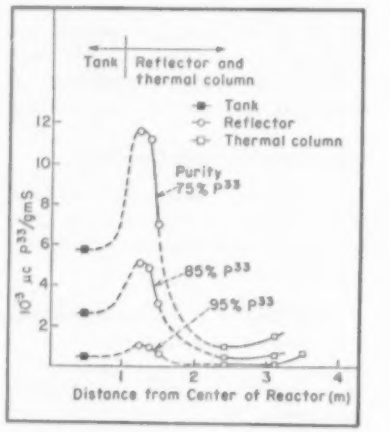

FIG. 2. P^{33} activity calculated from irradiation experiments after aging to certain purities. Irradiations were performed at Norwegian D_2O reactor

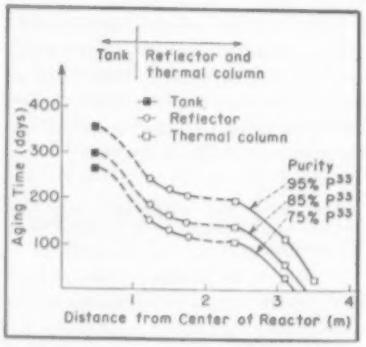

FIG. 3. Aging time required for P^{33} activities of Fig. 2 as a function of distance from center of reactor, with P^{33} purity as a parameter

were made in several parts of the Norwegian D_2O reactor at Kjeller. The results obtained have been combined with results obtained in this laboratory by G. Nilsson (*2*) from sulfur irradiations in the same reactor. Figure 1 shows the percentage of P^{32} in the total P-activity as a function of the distance from the center of the pile.

As seen from Fig. 1, P^{32} of very good purity can be produced by the irradiation of sulfur far out in the thermal column of a reactor. However, the flux and thus the total activity of P^{32} will decrease rapidly with increasing distance from the center of the pile. Another thing to be considered in connection with production of P^{32} with thermal neutrons is that S^{32}, according to Westermark (*1*), has a very low cross section for thermal neutrons, being only about 7% of that for fast neutrons. So if one wants to obtain P^{32} of good purity, i.e., containing little or no P^{32}, by irradiation far from the center of the reactor, the amounts of P^{32} produced will be very small (e.g., 0.0001–0.0002 μc P^{32}/gm S of 90% purity, when irradiation is performed for one month in the Norwegian reactor, having a central flux of $7{,}5 \times 10^{11}$ thermal neutrons/cm²/sec).

The other way of producing P^{32}, i.e., by the aging of sulfur that has been irradiated in the center of the pile, will yield a reasonable amount of P^{32} at the end of the irradiation, but during the aging for the production of relatively pure P^{32}, the amounts of the isotope will become small.

The preceding facts suggest that there might be places in the reactor where, by a combination of irradiation of sulfur with a thermal flux that is large compared with the fast flux, and of aging the irradiated sulfur, a maximum amount of P^{32} of a certain purity will be obtained. The final activity of P^{32} of a predetermined purity has been calculated from our experimental results. Figure 2 shows the P^{32} activities, formed by irradiation in the Norwegian reactor, after aging as a function of the distance from the irradiation position to the center of the pile for different final purities of P^{32} as a parameter. Figure 3 shows the corresponding aging time for getting different P^{32} purities as a function of the distance from the center of the pile. As seen from the diagrams, there is an evident maximum for the formation of P^{32} of a certain purity at 110–140 cm from the center of the pile, i.e., at 10–40 cm from the inner wall of the reflector,

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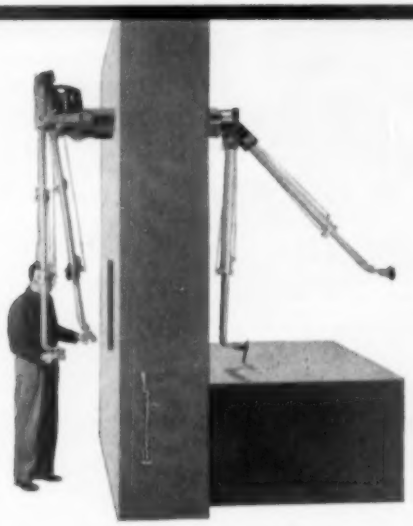

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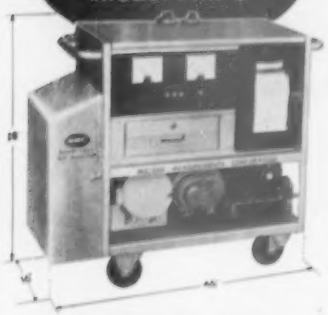

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but the final amounts of P^{33} are small and the aging time is very long for the production of P^{33} of a reasonable purity.

As a complement to the above experiments, a one-month irradiation of 1 kg sulfur has been made in the Norwegian reactor between the outside wall of the reflector and the concrete wall, i.e., about 2 m from the center of the pile. It yielded about 12 μc P^{32} with a purity of 27%, which means 0.3 μc P^{32} after aging the sulfur to a P^{32} purity of 85% of the total P activity. These data are, however, not quite comparable to those obtained in the other experiments, owing to the different irradiation positions.

Other Production Possibilities

As seen from the preceding results, the amounts of P^{32} produced as described are not very large, and even a sulfur irradiation in a reactor with a very high flux would yield small quantities of P^{32}. Thus, for producing larger amounts, one would have to consider other methods. For the production of P^{32} by neutron irradiation of sulfur there are four other possibilities than those mentioned: (1) the irradiation of sulfur with a low-energy neutron source, such as an Sb-Be one; (2) the irradiation of sulfur enriched in S^{32}; (3) the isotopic separation of radioactive phosphorus, produced by the irradiation of ordinary sulfur in the center of the reactor; (4) the use of the different recoil energies for P^{32} and P^{33} as calculated by G. Nilsson (*2*) to obtain a separation of the isotopes by neutron irradiation.

Possibility 1 is, in principle, a very good way of producing pure P^{32}. Unfortunately, until now, with only very weak sources of thermal neutrons available, the amounts of P^{32} that can be produced are very small. A 2.5-month irradiation of sulfur, performed in this laboratory with an Sb-Be source giving about 1×10^6 n/sec, yielded only about 0.003 μc P^{32}/kg S.

Possibility 2 means handling large amounts of a nonradioactive material in the isotope separator and irradiation in the reactor of small amounts of sulfur, while possibility 3 means the irradiation in the reactor of large amounts of sulfur compared to possibility 2, for getting a certain P^{32}-activity, and handling very small amounts of a radioactive material in the isotope separator. As seen, method 2 has several advantages over method 3. At present, only milligram quantities of moderately en-

riched sulfur (5–15% S^{33}) are available. Lately F. Spedding *et al.* (*3*) have found a new method for separating nitrogen isotopes in an ion exchanger; this method might be applied to sulfur isotope separation, for instance using the SO_3-SO_3^{--} system in an anion exchanger. This might give relatively large amounts of sulfur with a favorable S^{33}/S^{32} ratio.

Possibility 4 has been put forward by G. Aniansson and G. Nilsson (*2*). Aniansson suggested the irradiation of a suspension of colloidal sulfur, and Nilsson calculated the separation factor for the system P^{33} and P^{32} as a function of the radius of the sulfur particles for different recoil ranges—the P^{32} formed leaving the sulfur to a greater extent than the P^{33}. A suspension, however, means a rather large volume to be irradiated in order to get reasonable amounts of P^{33}. Practical experiments on the matter will be performed in this laboratory. There also might be other possibilities for using the different recoil energies of P^{32} and P^{33} to get a separation of the isotopes.

There are, of course, other methods of producing P^{33} than those using the neutron irradiation of sulfur, e.g., those requiring synchrotrons or cyclotrons, but we feel that an acceptable method of producing P^{32} by reactor irradiation would have many advantages.

A more complete account of this work will be given later.

* * *

This work is supported by the Swedish Atomic Committee.

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Gas-Cycle Reactors

Next month, NUCLEONICS will publish a special report on gas-cycle power reactors. Britain and France are building power stations that use gas-cooled reactors and steam turbines. This approach isn't held too promising for the U. S. But gas-cycle reactors (those using the reactor's cooling gas to drive the turbine) are attracting considerable attention. The nucleus of this thinking will be featured in the March issue.

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Heat Transfer in Reactors Cooled and Moderated by Water

By M. ALTMAN
General Engineering Laboratory
General Electric Company
Schenectady, N. Y.

Three separate designs are incorporated in every nuclear power reactor. These cover the thermal, nuclear, and mechanical aspects. The problems of thermal design are largely unappreciated. But incomplete understanding of such basic phenomena as boiling has created a serious bottleneck in nuclear-power development.

Here, basic problems of heat-transfer in reactors cooled and moderated by water are described to acquaint designers with these key factors in reactor design. For clarification, emphasis is placed on frontiers of heat-transfer reactor technology rather than on detailed information. Suggestions are made concerning factors needing clearer definition.

Steady-State Conditions

Coolant water enters the reactor core. Heat generated within the fuel elements is forced to diffuse into the coolant water by a driving force directly proportional to the temperature difference between the fuel-element surface and the coolant. The temperature difference needed can be calculated in the operating region of interest as

$$Q/A = h(T_s - T_w) \qquad (1)$$

where: Q/A = heat flux, Btu/hr/ft²; h = heat-transfer coefficient, Btu/hr/ft²/°F; T_s = surface temperature, °F; and T_w = local bulk water temperature, °F.

Inspection of Eq. 1 shows that high heat-transfer coefficients make it possible to use small temperature differences. There are two methods by which high heat-transfer coefficients can be obtained. The first utilizes high flow velocities; the second relies on disturbing the normally stagnant water film surrounding the heat-transfer surface by allowing surface boiling to take place. Of the two methods, the latter is by far the more effective one, but it is subject to disadvantages, which will be discussed.

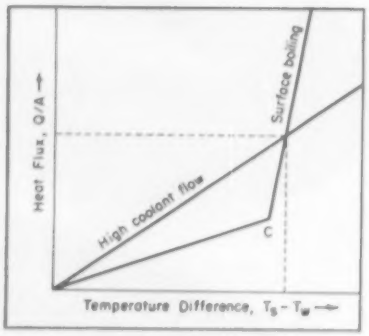


FIG. 1. Variation of heat flux and temperature difference when heat is removed with a high coolant flow (no boiling) and with surface boiling

Figure 1 illustrates how the same heat flux can be transported from fuel to coolant by the two methods. In the nonboiling case, pressures must be high to suppress boiling, and small values of $(T_s - T_w)$ are obtained by forcing the coolant to travel through the reactor core at high velocities. When it is considered that pressure drops are proportional to roughly the square of the velocity, it is clear that high heat-transfer coefficients must be paid for by high pumping power and increased reactor heat output.

In the surface-boiling case, pressure has been reduced to where the saturation temperature corresponds to point C. At this point, surface boiling sets in (neglecting the problem of required superheat). From point C on, the flow velocity has a negligible effect on the slope of the curve, which is very steep. It is clear then that the same quantity of heat can be removed by surface boiling, but at considerably lower surface temperatures, pressures, and flow rates. To illustrate this point, an example based on a hypothetical design will be used. This design has: total surface area = 4,000 ft²; water inlet temperature = 435° F; water outlet temperature = 475° F; flow velocity = 21 ft/sec; total power = 140 Mw; and there is a requirement that there be no surface boiling.

The average heat flux is calculated to be 123,000 Btu/hr/ft². The maximum normal heat flux can be calculated from the normal neutron-flux distribution. For reactors of the type being discussed, neglecting local effects near control elements, the maximum flux will be roughly twice the average flux. The location of the maximum surface temperature will vary. It depends on a combination of such factors as the magnitude of the heat-transfer coefficients, the mass flow rate, and the water temperature rise in the reactor. For a cosine distribution of power, the better the heat-transfer coefficient, the closer to the downstream end of the core will be the maximum surface temperature. In the limit, with very poor

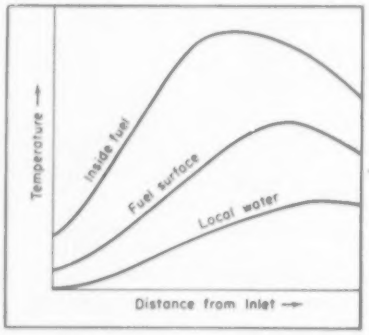
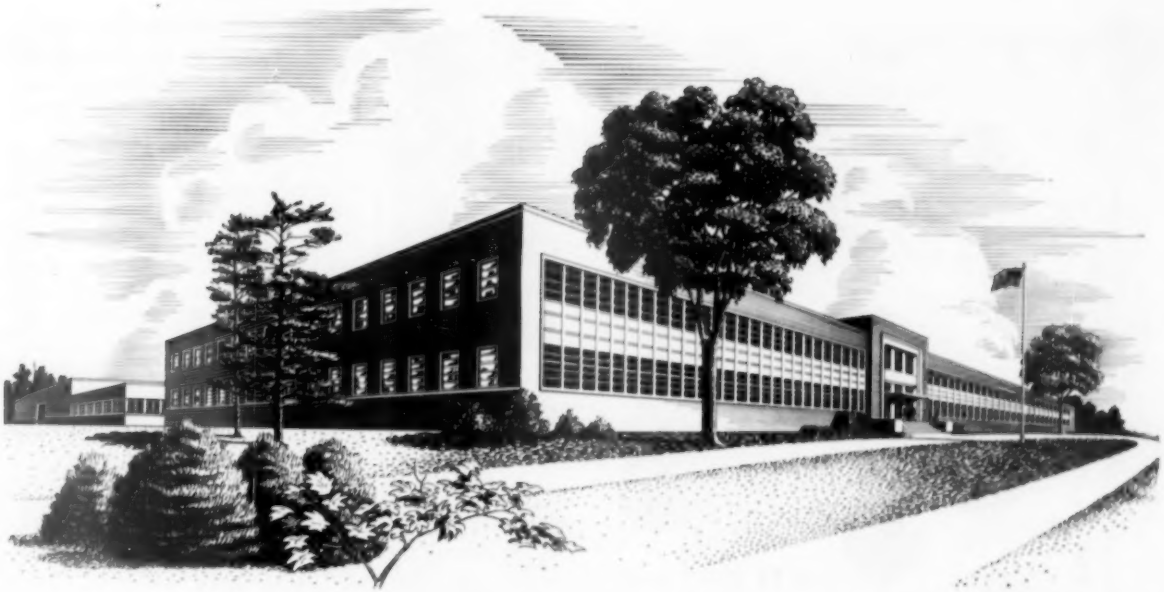


FIG. 2. Typical temperature distributions along length of core



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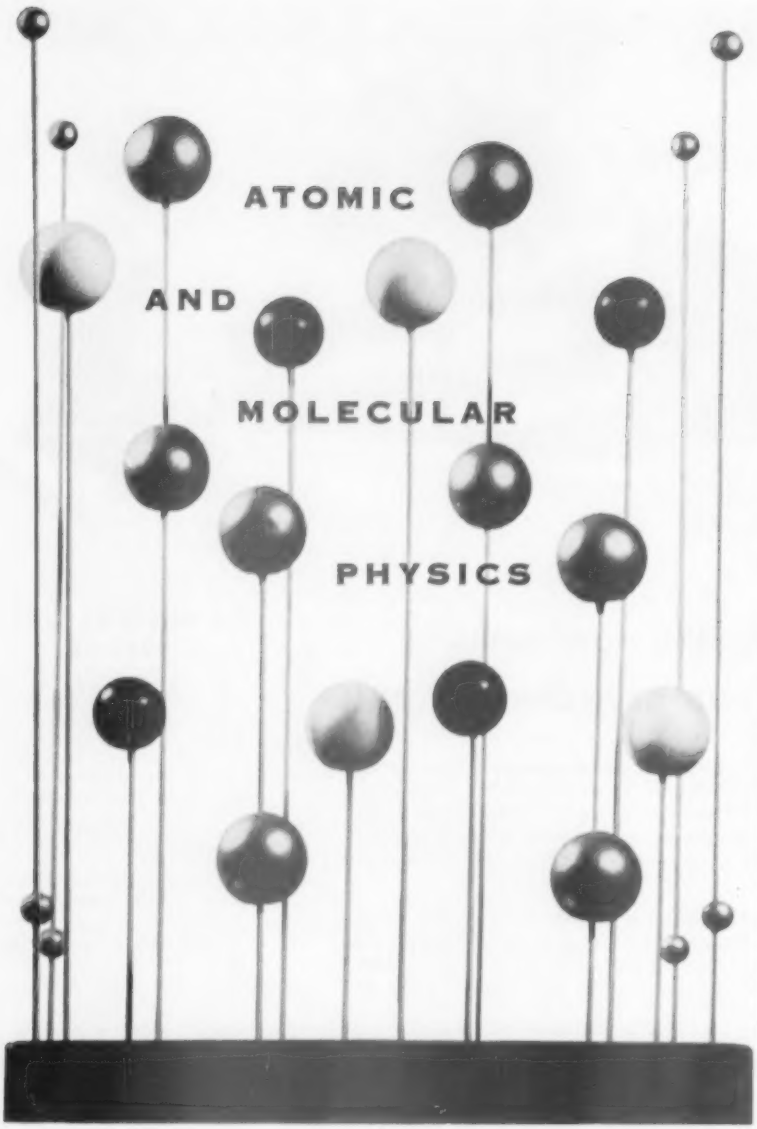

Molecular structure model, courtesy California Institute of Technology

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heat-transfer coefficients, the maximum surface temperature will occur in the center of the core. Figure 2 shows what the temperature distribution looks like along the core length.

The surface temperature varies only little over a region in the center of the downstream half of the reactor; for the case illustrated here the maximum surface temperature occurs at a plane roughly $\frac{3}{5}$ the length from the inlet end. The local water temperature and the heat flux at this point can be calculated, and the values are: heat flux = 213,000 Btu/hr/ft^2; local bulk water temperature = 465° F; heat-transfer coefficient = 8100 Btu/hr/ft^2/°F.

Substitution of these factors into Eq. 1 results in a temperature difference between the surface and the coolant of 26.3° F. The normal maximum surface temperature would then be 465 + 26 or 491° F.

However, this is only part of the story. It can be postulated that the neutron and heat fluxes are subject to local variations. It is entirely possible that heat generation along a maximum-flux channel might be greater than anticipated values as a result of such factors as distortions due to controls, nonuniform fuel distribution, or uncertainties in neutron-flux predictions. Local restrictions of the heat-transfer area might increase heat fluxes over and above these. Should all of these abnormal conditions coincide in a given location and should this be coupled with poor flow distribution, then it is possible that the local bulk water temperature might be as high as 471° F, and the temperature difference between the fuel surface and the coolant might be as high as 84° F. This would give rise to possible local surface temperatures of 545° F. Thus, even though most of the surface will be at temperatures of less than 500° F, it is necessary to pressurize the system to correspond to a saturation temperature of 550° F to suppress boiling at local hot regions.

Let this situation be contrasted to the alternative approach—where surface boiling is permitted. Let the exit water temperature be increased to 500° F. Most of the surface would then be at temperatures of less than 525° F, but the few local regions would exceed the saturation temperature, that is, they would transfer heat by surface boiling. However, because of the excellent heat transfer coefficients, the maximum surface temperature would be only a few degrees above saturation. In addition, high flow

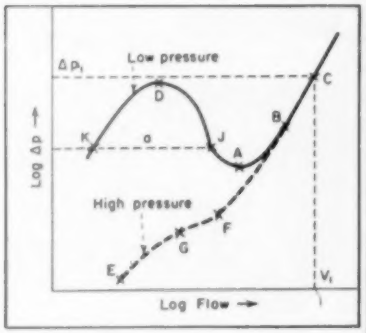

FIG. 3. How flow affects pressure drop in a single channel. Power is assumed constant

velocities are not needed, and the water temperature rise might be increased to 50° F, thus resulting in an inlet temperature of 455° F. This reduces the mass flow rate to 70% of its former value, and decreases the pressure drop through the core by about 40%. This will result in either less pumping power, or else smaller piping. The higher water temperatures can be used to produce either better steam or to decrease the required size of the boiler.

The possible use of this mode of operation depends on: (a) the effect of surface boiling on corrosion; (b) possible danger that surface boiling might produce density changes large enough to affect reactivity and flow distribution; (c) possible danger that safety of operation might be decreased. These factors will be considered critically later.

Effects of Boiling

This discussion will be limited to boiling that may occur under transients, or inasmuch as it affects the design of the normally nonboiling reactor.

The boiling curve. Figure 3 shows a typical relationship between pressure drop and flow through a channel of a reactor core. Point C represents a condition under which water is forced through a channel at velocity V_1 with a pressure drop of ΔP_1. As flow is decreased, the pressure drop will also decrease, but exit water temperature will increase. Finally, point B is reached where the surface temperature exceeds the saturation temperature, and surface boiling sets in. With further lowering of the flow rate, the effect of the bubbles becomes noticeable, and pressure drops will decrease at a slower rate as a result of the increased specific volume of the coolant. A further decrease in flow brings the exit water temperature to the saturation value,

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and bulk or net boiling sets in at point A. Additional decreases in flow produce increased pressure drops until the peak of the boiling curve is reached at D. From this point on, the effects of lower mass velocities overtake the effects of increased specific volumes, and pressure drops decrease again. Curve CFE is similar to the upper curve, but applies to much higher pressures of the order of magnitude of 2,000–3,000 psi.

Two dangers must be avoided. The first is the possibility of "vapor binding," and the second is the danger of "burnout."

Vapor binding. Vapor binding occurs when the available pressure is insufficient to force the steam-water mixture out of a channel. Point J in Fig. 3 represents an operating point that is inherently unstable, when the available pressure is represented by curve a. Any slight flow decrease would bring about a situation where the available pressure is too small to overcome the resistance to flow, and conditions will change until point K is reached. Point K represents a stable operating condition. However, the fraction of steam formed is so large that heat-transfer coefficients will be extremely small. The melting point of most metals will be exceeded, and destruction of the heat source will follow. Point B, on the other hand, is stable. A flow decrease brings about a higher available pressure than is needed, and this tends to re-establish the original operating conditions.

Inspection of Fig. 3 shows that point G is a stable operating point even though it is well within the boiling region.

Burnout. It is possible to destroy heat sources even when net boiling does not occur. Figure 4 is an extension of the surface-boiling curve of Fig. 1.

It has been pointed out before that very high flux rates can be obtained in

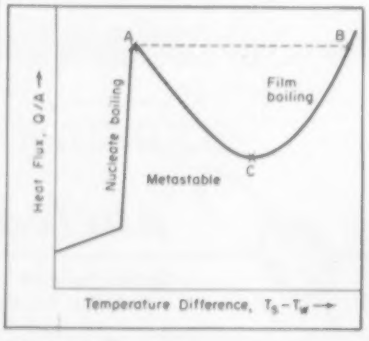

FIG. 4. Boiling curve

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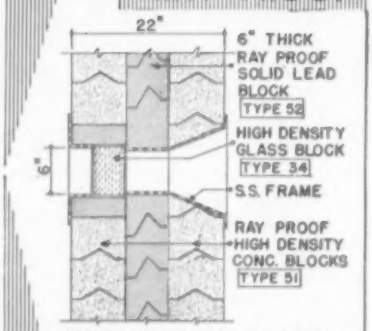

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the nucleate boiling region, with very small increase in temperature. It has been well established that the excellent heat transfer is produced by the formation of bubbles on the surface of the heat source.* The agitating action of the bubbles disturbs the normally stagnant water film on the surface, thus reducing the resistance to heat flow. It has been demonstrated that the driving force in this region is the difference between the surface temperature and the saturation temperature of the coolant. The bulk water temperature does not materially affect heat transfer. However, once the bubbles are formed, they must be condensed by the main coolant stream. The driving force for this is proportional to the difference between the saturation temperature of the coolant and the bulk water temperature. If this driving force becomes so small that bubbles are formed at a faster rate than they can be transported into the main coolant stream, then the bubbles coalesce, and a steam blanket is formed around the heat source. This steam blanket is a very poor conductor of heat, and very high temperatures are needed to force heat across this layer. In Fig. 4, A is the point where steam blanketing occurs. Once steam blanketing has occurred, the temperature increases to point B. In most cases, the temperature corresponding to point B is above the melting point of the heat source, and the source will be destroyed. For metals like platinum, which have very high melting points, it has been shown that a reduction of heat flux will produce curve BC. Experiments in the quenching of metals suggest that a metastable region exists that connects points C and A.

The two phenomena, burnout and vapor binding, represent severe limitations that must be allowed for in reactor design.

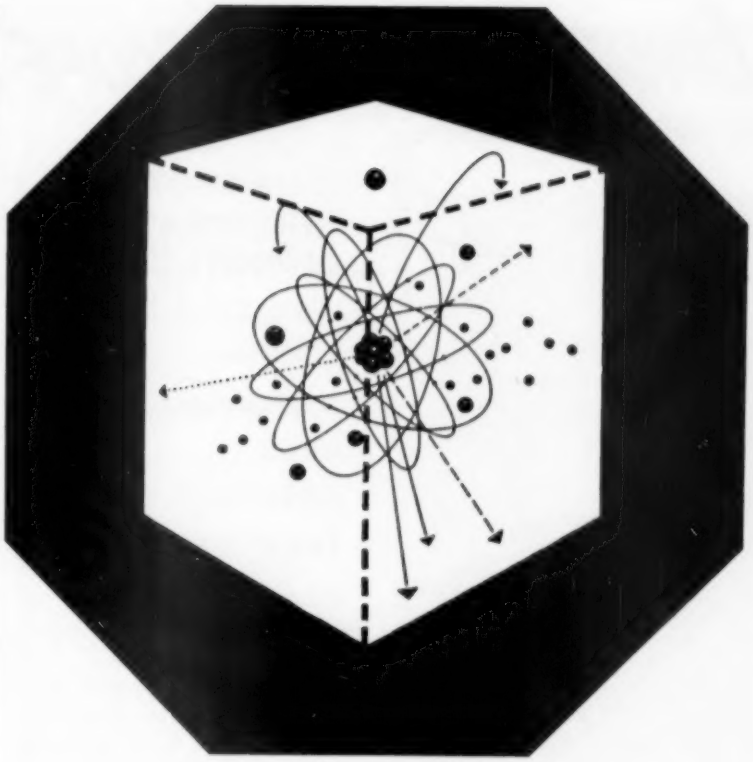
Several correlations are available for predicting the magnitude of the heat flux at burnout. One correlation is of the form

$$\frac{Q}{A} = C_1 \left(\frac{P}{P_c}\right)^{0.4} \ln\left(\frac{P}{P_c}\right) + C_2 G^m \Delta t^n \qquad (2)$$

where: Q/A = maximum permissible heat flux; P = pressure; P_c = critical pressure; G = mass velocity; Δt = subcooling, (i.e., $T_{\text{saturation}} - T_{\text{bulk fluid}}$); and C_1, C_2, m, and n are constants.

The first term of this equation cor-

* M. Jakob, "Heat Transfer," p. 624 (John Wiley & Sons, New York, 1949).



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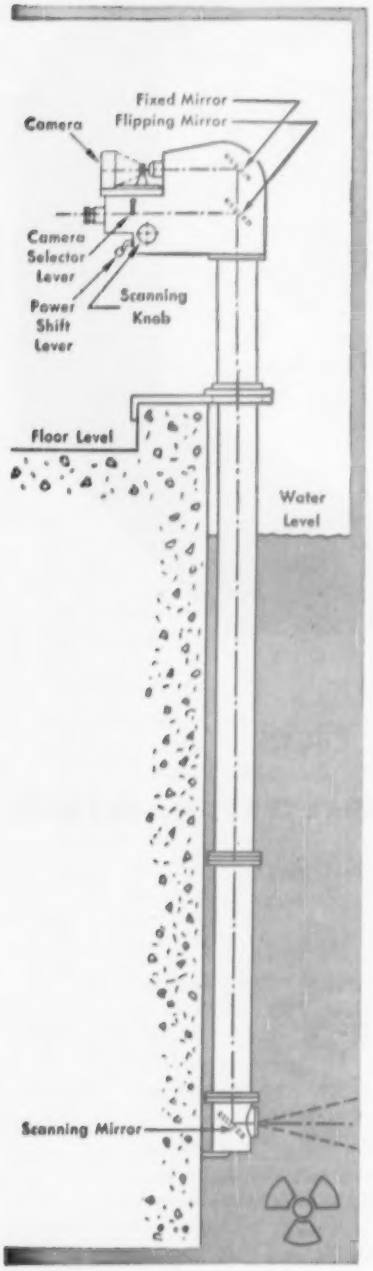

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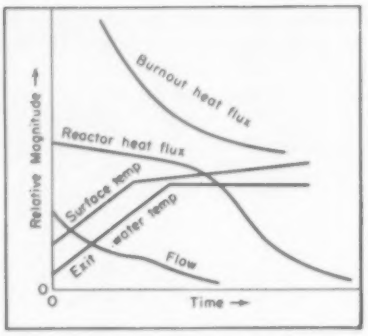

FIG. 5. How heat flux varies after pump failure. In this case, the large change in moderator density resulting from bulk boiling depresses reactor flux enough that the emergency cooling system can remove the heat produced. Reactor flux is never high enough to cause steam blanketing

responds to pool boiling, without forced circulation. The second term gives the contribution of added circulation. The constants C_1 and n appear to be independent of pressure, whereas C_2 and m are strongly affected by pressure. The constants have been evaluated from a variety of experiments. The second term is very much larger than the first term for normal conditions. To date, it is not reliably known what the effect of geometry is, nor how accurate the equation is in the region of low flow rates and subcooling values, where the first term contributes a large fraction of the total. The significance of this will now be considered.

Reactor Transients

Steady-state conditions can be disturbed by fluctuations in water flow, reactor power, pressure, temperature, and combinations of these. A complete discussion of all possible transients, normal and abnormal, is beyond the scope of this article. However, a serious possible accident will be described in detail.

It is conceivable that under certain conditions a complete pump failure may occur, and that the control elements might be inoperable. The possible consequences of such an occurrence are illustrated in Figs. 5 and 6.

At time zero the pumps fail, and the controls are inoperative. Flow begins to decrease at a rate depending on the primary-loop design and the inertia stored in the system. As a consequence, heat-transfer coefficients decrease, surface temperature of the fuel elements rises, as does the exit water temperature. Within a few seconds the surface temperature of the fuel elements reaches saturation, and nucleate

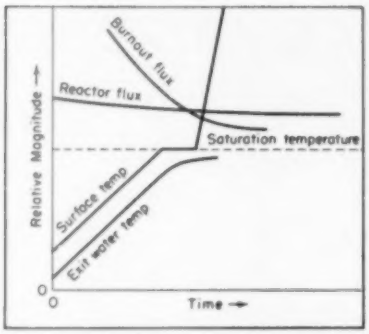

FIG. 6. After pump failure in this case, steam blanketing occurs before the exit-water temperature reaches saturation, film boiling sets in, heat transfer from the fuel elements is sharply decreased, and the fuel elements melt

boiling sets in. Very soon thereafter the water temperature approaches saturation.

Two possibilities are shown in Figs. 5 and 6. In Fig. 5 the relationship between burnout heat flux and reactor flux are such that reactor flux is always below the flux level that would produce steam blanketing. As a consequence, the water temperature will reach saturation, bulk boiling will set in, and the large density change in the reactor moderator will depress reactor flux to a value where the emergency cooling system can remove the heat produced. But in Fig. 6 it is assumed that steam blanketing occurs before the exit-water temperature reaches saturation. Heat transfer then becomes so poor that eventually all the heat produced is used in heating the fuel elements. Film boiling sets in (Fig. 4) and the fuel elements are destroyed.

Which of these occurrences takes place depends entirely on whether burnout fluxes are reached during the transient before boiling can be induced in the reactor.

Before definite conclusions can be drawn, it is necessary to examine the microscopic picture as well. Answers will have to be supplied for such questions as: What happens when boiling starts in a region of a subassembly? What are the consequences of possible channeling effects of the coolant? If it is true that the safety of operation depends on the burnout flux at values of flow and subcooling that occur when the coolant approaches saturation, would it not be safe to operate close to saturation under steady-state conditions? What are the criteria for flow stability within subassemblies and between subassemblies?

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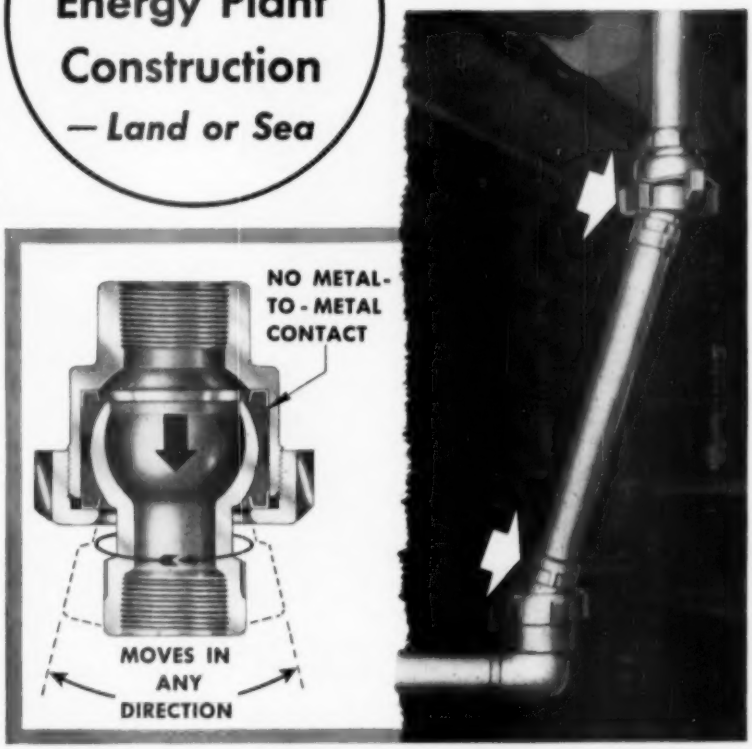

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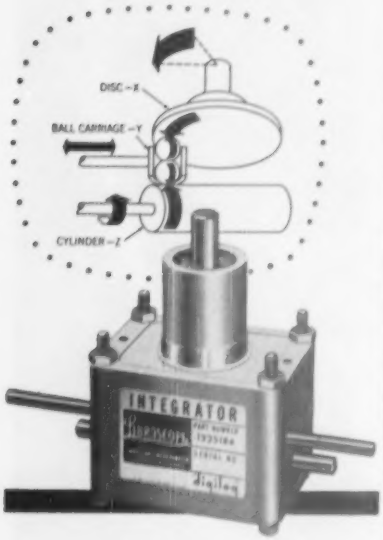

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TECHNICAL ADVANCES

Transmission Multiplier Promises Higher Speed Westinghouse scientists have taken advantage of the secondary-emission electrons generated by primaries passing through a thin film to make a photomultiplier that can be much faster than conventional types. The new device is at an early developmental stage, but already shows impressive performance.

The individual dynodes are sandwiches consisting of a 100-mesh 50%-transmission photoetched copper screen (for support) onto which is evaporated a 100-Å layer of SiO (for strength) followed by a 300–600-Å layer of KCl surmounted by a 15–25-Å layer of gold. Primary electrons enter through the gold layer, which serves to scatter and slow down the primaries and produce some secondaries. Still more secondaries are produced in the insulating KCl layer. Significantly, not many primaries get through, and the emerging secondaries are quite low in energy.

For films described maximum yields of 6–8 (adjusted for screen transmission) were observed for 3-kev primaries. More than 90% of the emerging electrons have energies below 6 ev and only 5% are more energetic than 50 ev. This homogeneity makes for simpler electron optics and less spread in transit times. This is helped further by the fact that the films lend themselves to a photomultiplier geometry in which the dynodes are successive plane parallel films. This drastically simplifies the electron optics and permits large cathode and dynodes.

To study transit-time problems E. J. Sternglass and M. M. Wachtel, who did this research, built a demountable 7-stage tube. Its gain was 2.2 per stage. Dynode spacing was 0.20 in.; voltage between stages was 3.3 kev. Pulse rise times were measured to be 1×10^{-9} sec with a delay of $3 \pm 1 \times 10^{-9}$ sec. Theoretically one expects this from interdynode-transit-time considerations alone; thus the delay in the secondary-emission process is $<10^{-10}$ sec. The transit times can be made still smaller with higher gradients.

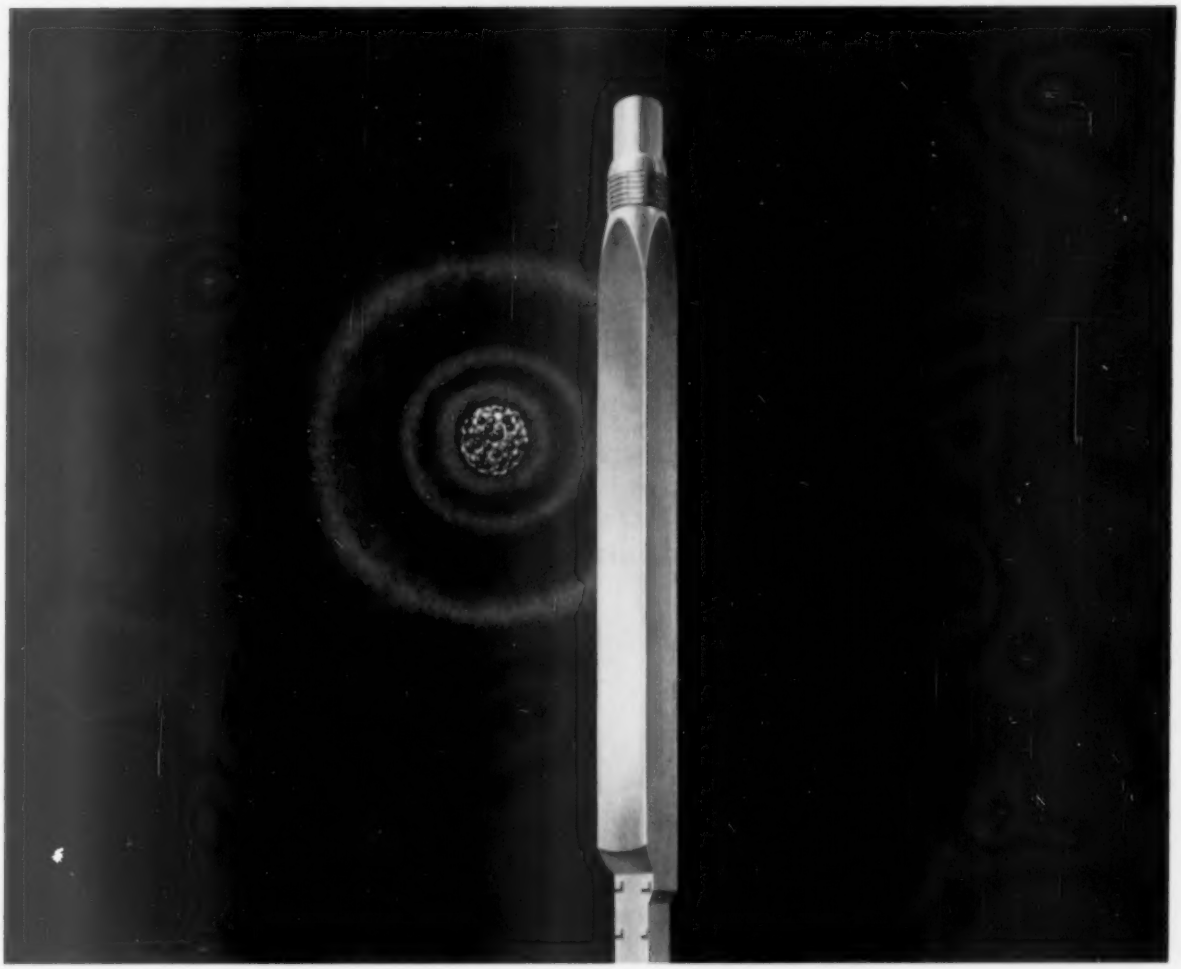
Record-Sized NaI Crystal Goes to Work Shakedown tests are on for a 75-lb NaI(Tl) crystal recently acquired by the physics division of Oak Ridge National Laboratory. The 75-lb crystal is in the shape of a 9¼-in.-diameter 6-in.-high cylinder topped by a 45-deg cone truncated at 3¼-in. diameter. A ½-in. hole drilled into the conical end reaches to the approximate center of the crystal.

Three 5-in. DuMont 6364's are optically connected to the flat end with epthalalogical white petrolatum. This assembly is surrounded with 0.005-inch aluminum foil that has been treated inside with a reflecting coat of α-alumina Linde A saphire powder mixed with sodium silicate. The seal is made around the tubes with Apiezon Q.

This assembly is supported in an aluminum cage by three 1/16-inch steel belts. Bicycle spokes are used for supports. Thus, a small amount of material surrounds the crystal so that any radiation escaping the crystal will not be scattered back to the crystal.

P. R. Bell and R. C. Davis report that with the sample placed at the bottom of the hole at the center of the crystal the total efficiency is essentially 100% up to 300 kev; at 1 Mev it is 90%. The lowest efficiency is 76% at 5 Mev, beyond which it becomes higher gain due to pair production. Thus sum pulses can easily be seen on the curve of Co^{60}.

Fission-Recoil Energy for Chemical Processing Harteck and Dondes of RPI have conducted experiments that point the way to more effective use of nuclear reactors for chemical processing. Basically they use the energy of fission more directly by tapping the ionization effects of fission fragments rather than using incidental reactor radioactivities as is done at present. They conducted the experiment of adding 5 mg of enriched U^{235} oxide to a 20-ml reaction vessel containing gases being irradiated in the BNL reactor. This increased the dose by a factor of 60, even though only 10% of the fission particles emerge from the powder grains used. Decomposing CO_2, some 25% of the nuclear energy is stored as chemical energy. Six molecules of NO_2 and three molecules of N_2O are formed for each 100 ev expended in pressurized air (which turns out to be the optimum O_2-N_2 mixture!). The economics of the process are promising.



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BOOKS

You and the Atom

By GERALD WENDT with a preface by LUTHER H. EVANS (Whiteside, New York, by arrangement with UNESCO, 1956, 96 pages, $1.95).

"This book is a guidebook to the newly discovered land of atomic energy in which the scenery is all science and the roads are education." So the author of this lively book describes his work.

Written for UNESCO to mark the occasion of the Geneva Atoms-for-Peace Conference, it has as one of its purposes to serve as an introduction to the new world of atomic energy and its peaceful applications for educators—for those who write for the public as well as those who teach in schools. Yet so successful is the author in bringing his explanations down to a common denominator and in illustrating them with vivid and striking similes that the book will surely be found useful at the college undergraduate level, possibly in high schools as well.

The book covers energy, nuclear fuels, sources, reactors, power, radioactivity, tracers, and prospects. The author's qualifications were amassed during a many-sided career: since studying radioactivity in France in the laboratories of Mme. Curie, he has been professor of chemistry at the University of Chicago and dean of chemistry and physics at Penn State, science editor of two national magazines, head of UNESCO's Division of Teaching and Dissemination of Science, and is the author of three earlier books on atomic energy. He is now director of the Institute for Atomic Developments, devoted to education of the public.

For an explanation of the benign aspects of atomic energy that is couched in simple terms, yet is scientifically punctilious, "You and the Atom" fills a need.

Power Reactors

Volume 3 of the Proceedings of the International Conference on Peaceful Uses of Atomic Energy; Geneva, August 1955 (United Nations, New York, 1955, 393 pages, $7.50).

This is the first to be published of the 16 volumes that will constitute the complete verbatim record of the United Nations' conference last summer. As the conference was historic and monumental, so it is apparent from this first volume that the proceedings in themselves will be quite unique in the annals of nuclear literature.

Just look at the contents of Volume 3—never before have there been brought together under one cover papers by the world's foremost reactor specialists, from the West and the East, summarizing most of the important reactor ideas and schemes that had been developed up to that time. Certainly this volume, which covers what most of those present at the conference regarded as the most exciting sessions, should be in the library of everyone seriously concerned with reactors.

For those who were at Geneva, the record of the discussions of papers will recall the tension and drama during the early days of the meeting when questions by Western participants aimed at Soviet speakers and vice versa had people sitting on the edges of their seats. These discussions and the information that came out of them will also be of tremendous interest to those who were not present.

The proceedings will contain the full text of all papers submitted to the UN and accepted (a total of 1,067 papers), the full text of the abbreviated versions of the 450 papers selected for oral presentation, and the entire record of the discussion periods. Volume 3 has three papers on fuel cycles; 27 on operating experience and design descriptions of existing and proposed power reactors. Also included is a reactor catalog that contains some data from the papers as well as other information available before the conference.

ALSO OF NOTE

The Place of the Atom in Your Business. This conference, in conjunction with the Nuclear Congress (Cleveland, Dec. '55), was sponsored by the Cleveland Engineering Society. Speakers included Lewis Strauss, Sen. Clinton Anderson, Eugene Zuckert, L. R. Zumwalt, R. S. Morse, A. W. Meyer, and O. B. Falls, Jr. Papers and abstracts are available from *Cleveland Engineering Society, 2136 E. 19 St., Cleveland 15, Ohio ($1.00 per copy)*.

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NUCLEAR CALENDAR

Feb. 28–29—Fifth Scintillation Counter Symposium, Washington (*Shoreham*). Sessions will cover photomultipliers and circuits, scintillators, particle detection and special problems. Contact G. A. Morton, RCA Laboratories, Princeton, N. J.

March 19–21—Reactive Metals Conference (AIME), Buffalo (*Statler*). Will discuss rare or difficult-to-process metals such as Ti, Zr, Be, U, Th, Ta, Re, Cb. Contact AIME.

March 19–22—Institute of Radio Engineers, annual meeting (Professional Group on Nuclear Science meets on 20th), New York (*Waldorf*). Contact IRE.

April 3–7—6th annual conference on High Energy Nuclear Physics (AEC & Natl. Sci. Foundation), Rochester, N. Y. Properties and interactions of nucleons, pions, heavy mesons and hyperons. Contact Prof. Arthur Roberts, Univ. Rochester.

April 5–6—Conference on Magnetic Amplifiers (AIEE, IRE, ISA), Syracuse, N. Y. Technical and tutorial sessions on theory and manufacture of magnetic amplifiers and components, and an exhibit. Contact Fred J. Lingel, GE, Electronics Park, Syracuse.

April 17–18—Regional conference, Atomic Industrial Forum, Atlanta, Ga. The importance of atomic energy to the South, energy supply and requirements in the South, present status and prospects of atomic development. On 19th the conference moves to Oak Ridge for visits to research facilities. Contact D. J. Scherer, AIF, 260 Madison Ave., N. Y. 16.

May 14–16—Conference on Basic Mechanisms in Radiobiology (National Research Council), Highland Park, Ill.

May 15–16—Industrial Nuclear Technology Conference (co-sponsored by Armour Research Foundation and NUCLEONICS), Chicago. Will cover uses of radioactivity in industry and research. Contact John Forewalter, ARF, 55 East 33rd St., Chicago, or NUCLEONICS, 330 West 42nd St., N. Y.

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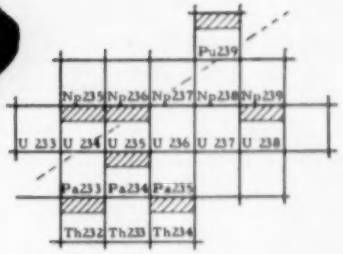

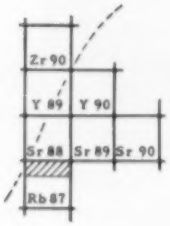

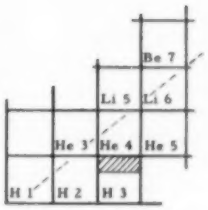

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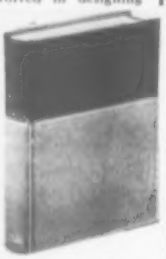

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LETTERS

Test Tube Reactor

DEAR SIR:

I have read with interest the article "Test Tube Research Reactor" by H. M. Busey and R. P. Hammond in the November issue of NUCLEONICS. The article is quite thought provoking and I am glad it has appeared in journal form.

The design appears to be intermediate between the "water boiler," which operates at atmospheric pressure, and the Homogeneous Reactor Experiment, which operated at high pressure and with forced circulation. The test-tube design retains the simplicity of convection cooling along with the characteristic found in the HRE of a "clean" core, i.e., no stainless-steel cooling coils are located in the active region. Both of these features are very much to the good.

In reading the article, several observations and questions come to my mind. Following are a few of them:

1. The second sentence may have been accurate when the manuscript was prepared but is no longer quite true.

2. The authors do not estimate the actual U^{235} holdup. I would judge that it is four or five times the critical mass and will be interested to learn its true value.

3. Nor do I find an estimate of the gas pressure after long-time operation at 100 kw. The accumulation of radioactive gases, which are not affected by the recombiner, makes the removal of the cover a somewhat more complicated procedure than the simple statement on the bottom of p. 74 might lead one to believe.

4. The reactor operates with a very corrosive liquid. If trouble should develop in the reactor (a leak in the cooling system, recombiner trouble, etc.), skilled technicians and expensive remote-handling equipment are required to effect repairs on the radioactive assembly. Such specialized equipment and trained personnel are found only at the national laboratories or similar organizations. For all practical purposes then, if the reactor were located at an average-sized university or small laboratory, any troubles developing after high-power operation would necessitate that the entire assembly be discarded—a procedure in itself not entirely simple.

5. I wonder if the remarks under "Safety" might be a little misleading to the uninitiated. As I understand procedures of the Advisory Committee on Reactor Safeguards, this Committee comments only on specific installations, and then only in the framework of the associated exclusion area, meteorological and hydrological factors, etc. The AEC (through its contractors) can build any type of experimental reactor it wants to and, within reason, operate it in any fashion it so desires—providing it meets certain requirements relative to exclusion area or gastight building the ACRS will raise no objection. At least this has been the record in the past. Would the ACRS be happy about the operation of a test tube reactor without attendant in an open building in a downtown location?

6. I presume the statements about stability and power-level adjustment by cooling-water flow are extrapolations from "water boiler" experience. The same holds true for the dependence on sensitive relays to operate the safety circuits. In some quarters, these relays are not regarded as being particularly reliable.

7. The estimated costs of the reactor assembly and the instruments appear to be somewhat low, especially if the instruments are to be purchased from regular commercial sources. And there is no provision for spares, a necessity when away from a National Laboratory, nor are installation costs set down. I hasten to add that even if the reactor, instruments, spares, and installation should come to double the estimated figures, the cost is still very reasonable.

I strongly concur with the authors in their hope that the test tube reactor they describe will be constructed. Further, I think it desirable that it be built at some medium-size institution away from an AEC laboratory. Cost figures and operating experience then will be accurate indications of what a university or small research organization could expect from this design.

—WILLIAM M. BREAZEALE
Professor of Nuclear Engineering
Pennsylvania State University
University Park, Pennsylvania

DEAR SIR:

We are glad to supply answers to some of Dr. Breazeale's questions. Many details of the design would have

to be varied to suit the particular application, and were therefore omitted from the brief report.

For the 8-in.-diameter vessel illustrated, the U^{235} inventory is estimated to be about 1.5 kg, of which about 50% is estimated to form the core (the "core" includes part of the central chimney). For a heavy-water-moderated graphite-reflected version, the portion of the vessel below the heat exchanger might be enlarged to form a 26-in.-diameter sphere. For this condition an inventory estimate would be about 0.66 kg, of which about 95% is "core." A D_2O reflector would further reduce inventory. We are indebted to Dr. George I. Bell of this Laboratory for assistance in these estimates.

The permanent gas formation is estimated at about 10 cm^3 (STP) per megawatt-day of operation. This quantity will not affect normal operations, but when the container must be opened the gas would have to be disposed of by means of a charcoal trap or other method. Of course, the soup would also be removed before opening the vessel.

We do not believe that maintenance of the system should necessitate remote-handling equipment. Of course, enough skill is required to do the mechanical jobs and to read a monitoring instrument. Our belief is based on experience in installing and maintaining the recombiner system of the Water Boiler.

Mention of the experimental power reactor in our report was certainly not intended to imply that any research reactor should be run unattended.

—Philip Hammond and Harold Busey
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Applying Radiation to Industry

That's the subject of a case-study special report scheduled for the May issue of NUCLEONICS. It will cover uses in both industrial research and production processes under the headings

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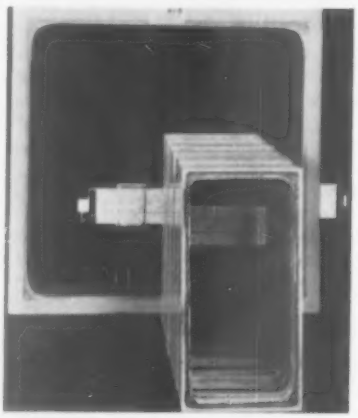
RADIOACTIVITY MATERIALS AND APPARATUS



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Tube and Intensifier

New X-ray tube used with electronic image intensifier provides inspection at remote points over closed TV circuit, eliminating radiation hazard to viewing personnel. Intensifier increases image brightness 1,200 times above ordinary fluoroscope.—Research & Control Instruments Div., North American Philips Co., Inc., Mount Vernon, N. Y.

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Model No. 4 repeat cycle timer uses two cold-cathode triodes; independent adjustability of both on and off cycles from 0.1–12 cycles provided; output is spdt relay with 5-amp contacts.—C. G. Wilson & Co., 1915 Eighth Ave., Huntington, W. Va.

Shielding Bricks

New design for lead bricks with crescent-shaped cross section permits shield wall to follow any geometric path, eliminates corners, reduces weight, uses fewer pieces. All vertical radiation leakage is eliminated; if V-notch ends are specified, hori-

Products Index

Radioactivity Materials and Apparatus 82
Literature Available 87
Industry Notes 89

CHECKING OUT ANOTHER L&N REACTOR CONTROL "PACKAGE"

The cubicle being checked out here is typical of the "package" control systems we are now supplying to regulate nuclear reactors for education, research, and steam power generation. No mere assembly projects, these packages are entirely designed, engineered, and fabricated at L&N for reactor control at all power levels. All include safety and interlock circuits for safe operation under all conditions.

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A booklet, "Control Systems for Nuclear Reactors," tells the whole story. It's free from our nearest office, or from Leeds & Northrup Co., 4936 Stenton Ave., Phila. 44, Pa.

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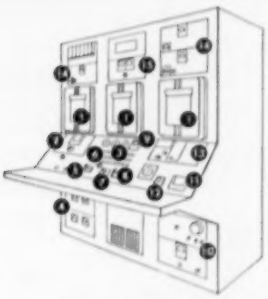

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9. *Control Rod Position Indicator*
10. *Log Count Rate & Linear Amplifiers*
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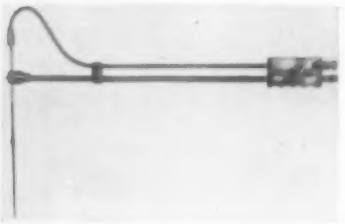
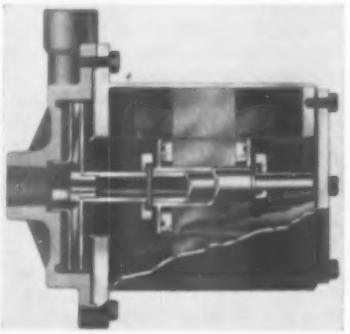


Remote Pipette

Control device adds 2-foot extension to hands or lips; grasps and releases glass tube, "sucks up" solution into pipette by means of syringe in handle; manually operated. Will accomodate almost any size pipette; replaceable parts where contamination may occur.—Atomic Center, 489 Fifth Ave., New York 17, N. Y.

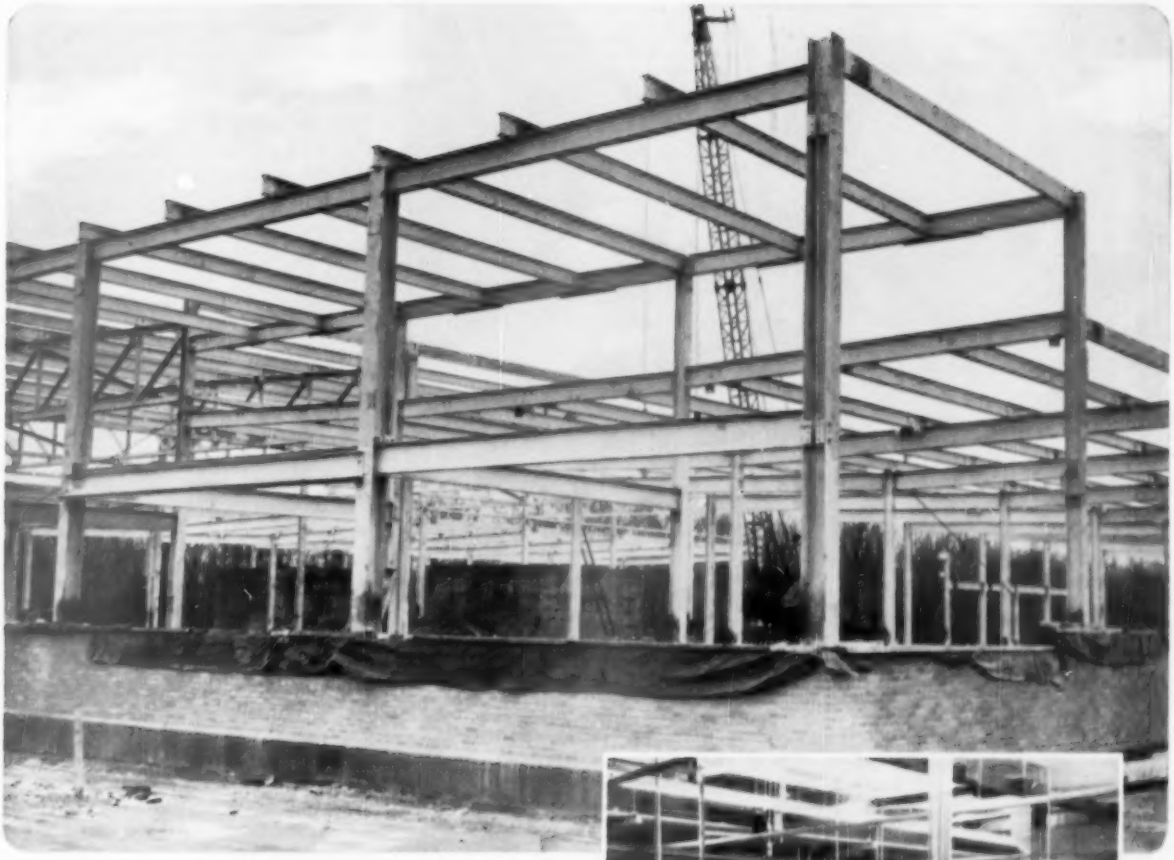
X-Ray Spectrograph

New multielement indexing X-ray spectograph covers range of 71 elements, gives percentages of as many as 24 in specimen. X-ray tube maximum ratings are from 100 kv, 25 ma through 50 kv, 50 ma; transformer delivers up to 50 ma at voltages up to 100 kv; stepless voltage control has range of 15 to 100 kv.—Research & Control Instruments Div., North American Philips Co., Inc., 750 South Fulton Ave., Mount Vernon, N. Y.



Sealless Pumps

New Model S sealless centrifugal pumps (above), ¾ to 3 hp units, offer leak-proof corrosion resistant service at capacities to 170 gpm, heads to 150 feet. Fabricated parts can be clad with variety of corrosion-resistant metals; new semifloating graphitar bearings give 400 percent more bearing area, can be replaced from front or back without special tools, without breaking piping con-



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nections.—Chempump Corp., 1300 E. Mermaid Lane, Philadelphia 18, Pa.

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For determining chemical purity Cryoscope unit measures freezing point to within 0.001° C from +20 to −30° C in 1 min. Related instrument is Fiske Osmometer for determining osmotic pressures, molecular weights, etc., by freezing-point. —Advanced Instruments, Inc., 21 Oakcrest Rd., Boston 92, Mass.

Vacuum Doughnuts, Ceramics

Low-loss vacuum-tight ceramic material, used in many accelerators, can be cast in a variety of shapes, large or small. Main properties: dielectric loss at 50 mc: 0.00035; dielectric constant: as desired in range 6.5–24; modulus of rupture: 17–24 kilopsi; good thermal shock resistance. Also available are cast shapes in pure Barium titanate with dielectric constants to 5,000.—Shakespeare Ceramics, 2300 Washington St., Newton Lower Falls 62, Mass.

■

Ferrophosphorus for shields. Ferrophosphorous for mixing in concrete to make shields with density up to 300 lb/ft³ is available in crushed form from three plants.—Victor Chemical Works, 155 N. Wacker Dr., Chicago 6, Ill.

Disaster badges. Special film badges are available for fire or disaster. They register from 1 to 500 r and can be stored for at least 4 years without deterioration.—St. John X-ray Laboratory, Califon, N. J.

Portable scintillation counter. Atomlab Model WTSC-5, well-type, permits one-man handling through constructing shield as series of 2-inch-high interlocking rings, each weighing less than 30 pounds.—The Atomic Center, 489 Fifth Ave., New York 17, N. Y.

Atomic battery. ATBEE, 17,000-volt, single-cell battery, is 1 in. in diameter, 1⅝ in. high, weighs 5 oz, has maximum current of 1 milliμamp. ATBEE has a 25-year half-life; uses a 2- or 10-mc strontium-90 beta particle source.—Radiation Research Corp., 140 E. 59 St., New York, N. Y.

Summation counter. High-speed pulse-actuated electromagnetic bidirectional counter operates to 60 cps in either direction or to 50 cps random

input on d-c; available for a-c with external rectifier.—Nemeth, Inc., 2223 S. Carmelina Ave., Los Angeles, Cal.

Gamma-ray projector. New radiography source is available in three sizes: equipped for both spot and panoramic shots. With shutter closed, even photographic materials can approach the projector without fogging.—Metal & Thermit Corp., 100 E. 42 St., New York 17, N. Y.

Film thickness gage. Step Gage, plate of special glass in plastic case, measures thickness of thin transparent film by means of color comparison in range of 2 to 16 microin.—Sunshine Scientific Instrument, 1810 Grant Ave., Philadelphia, Pa.

Radiation shielding. Hevimet has specific applications including shielding in atomic submarines; cost is greater than that of lead, but Hevimet has density of 17.2; tensile strength is 100,000 psi; yield strength is 75,000 psi, elongation is 2%.—Carboloy, General Electric Co., Detroit 32, Mich.

Plastic steel. Devcon, 80% steel and 20% plastic, handles like modeling clay. Two hours after addition of special hardening agent the mixture becomes rigid. Can be used for shielding or die making.—Chemical Development Corp., Danvers, Mass.

Linear accelerators. Designed for medical or industrial applications, 4-Mev linear electron accelerator weighs under 1,000 lb complete.—Stanford Laboratories Co., 1661 Broadway, Redwood City, Calif.

Radioactivity absorber set. A packaged absorber set of 22 calibrated aluminum absorbers covers a range of 0–900 mg/cm².—NRD Instrument Co., 6425 Etzel Ave., St. Louis 14, Mo.

LITERATURE AVAILABLE

Film badges. New specification sheet describes film badges for personnel protection. 2 p.—Nuclear-Chicago, 229 West Erie St., Chicago 10, Ill.

Electron tubes. Catalog lists special purpose electron tubes. 21 p.—Industro, Inc., 649 Broadway, New York 12, N. Y.

Radioisotope equipment. Catalog C-201 describes instruments used in

The "Ceramo" thermocouples to be used to measure temperatures for evaluation of efficiency and safety of the "Seawolf's" atomic reactors have Stainless Steel sheaths and Chromel-Alumel thermocouple wires.*

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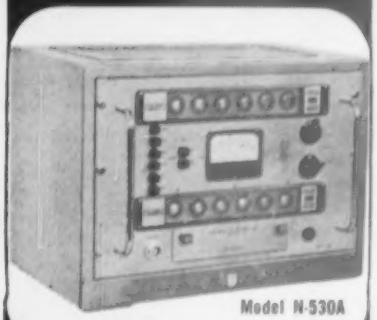

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medical radioisotope measurements. Clinical applications given. 14 p.—Dept. D, Berkeley Div. of Beckman Instruments, Inc., 2200 Wright Ave., Richmond 3, California.

Radiography. Supervoltage radiography as inspection and quality control tool is described in Bulletin R. Contains curves, tables, checklist of major characteristics, case studies. 24 p.—High Voltage Engineering Corp., 7 University Road, Cambridge 38, Mass.

Nuclear test reactor. Bulletin GER-1123 describes, illustrates design features and construction of light-water and oil-moderated nuclear test reactor. 20 p.—General Electric Apparatus Sales Div., Schenectady 5, N. Y.

Nuclear valves. 7-section catalog A-155 lists, illustrates nuclear and chemical industry valves and controls.—Associated Valve & Engineering Co., 1150 West Marquette Rd., Chicago 21, Ill.

Radiation measurement. Bulletin NER-1 (by H. Palevsky, BNL) surveys radiation detectors, formulas, tables and graphs fundamental to radiation measurement. Designed to serve in design and construction of ion chambers.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia, Pa.

Beta activity. "Counting Soft Beta Emitters with Liquid Phosphor Techniques" describes process, including sample preparation, instrument operation, advantages and limitations of method. 11 p.—Technical Measurement Corp., 140 State St., New Haven 11, Conn.

"Atom in Our Hands." Production processes, peaceful uses of atomic energy described in booklet. 44 p.—Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17, N. Y.

Lubricants. Booklet describes flourocarbon oils, waxes and greases. 16 p.—Chemical Manufacturing Div., M. W. Kellogg Co., P. O. Box 469, Jersey City 3, N. J.

Medical instruments. Equipment for diagnostic measurement in radioisotope laboratory described in catalog.—NRD Instrument Co., 6429 Etzel Ave., St. Louis 14, Mo.

Instrumentation. Bulletin NER-2 describes processes and instrumentation

Radiation Applications

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in production of atomic energy. 22 p.—Brown Instrument Div., Minneapolis-Honeywell Regulator Co., Philadelphia 44, Pa.

Ratemeter. Folder covers operation and application of six-digit high-speed scaler for proportional, scintillation or Geiger counting. 4 p.—Electronics Div., North American Philips Co., Inc., 750 South Fulton Ave., Mt. Vernon, N. Y.

Rare Earths. Price list for rare earth elements. 1 p.—Research Laboratories of Colorado, Inc., P. O. Box 307, Newtown, Ohio.

Beryllium. Complete line of beryllium-alloy products described in directory. 20 p.—The Beryllium Corp., Reading, Pa.

Clad metals. Data sheets including specifications, technical information, applications. 30 p.—Joseph Kinney Co., Inc., Carnegie, Pa.

Chemicals. Folder outlines principal chemicals used in atomic program.—General Chemical Division, Allied Chemical & Dye Corp., 40 Rector St., New York 6, N. Y.

Magnetic shields. Catalog describes materials, design, fabrication of magnetic shields; includes 33 working drawings. 36 p.—Magnetics, Inc., Butler, Pa.

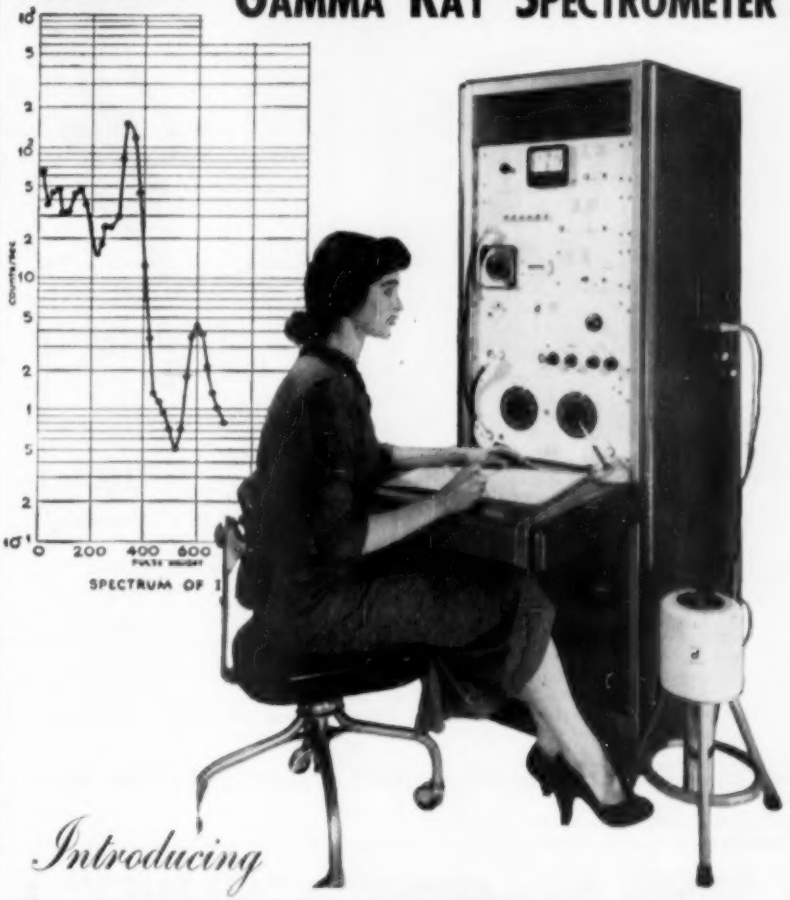
INDUSTRY NOTES

▶**Murray E. Volk** has organized the **Volk Radiochemical Co.,** with offices at 5412 N. Clark St., Chicago 40, Ill. The new company will specialize in the manufacture and supply of labeled compounds and allied services. Dr. Volk had been associated with Nuclear-Chicago.

▶**AMF Atomics (Canada) Ltd.,** a new subsidiary of American Machine & Foundry Co. with headquarters in Toronto, represents the company's first expansion of atomic operations outside the U. S. Gen. Walter Bedell Smith, board chairman and president of AMF Atomics Inc., will also hold the same positions in AMF Atomics (Canada). Denton Massey, director of customer relations for AMF Atomics, will serve as general manager for the Canadian sister firm.

▶**Westinghouse Electric Corp.** has awarded a contract to **Greer Hydraulics, Inc.,** for research and develop-

Precision GAMMA RAY SPECTROMETER



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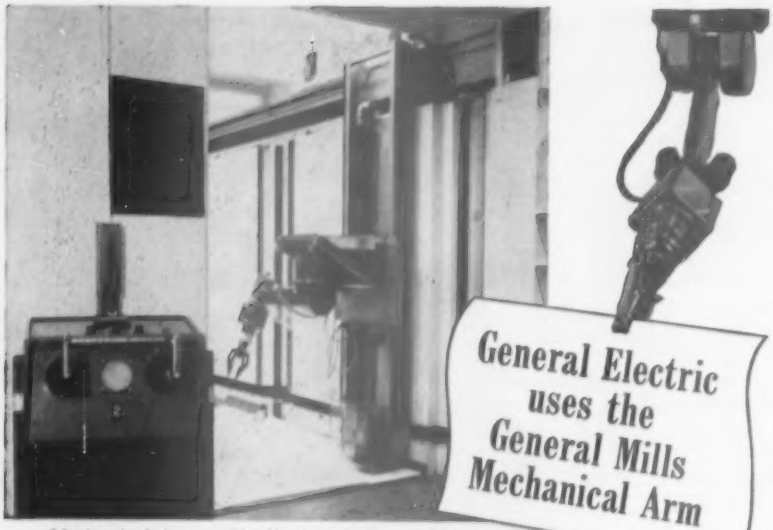

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ment work on a gas pressurizer for the primary circuit of atomic power reactors, in connection with a Westinghouse assignment from the Navy. To be studied are the effects of radiation on the operational life of bladder-type hydro pneumatic accumulators, and on the materials used in their construction. The Greer accumulator is used in industry as a means of storing hydraulic energy and of damping pressure surges and pump pulsations in hydraulic lines.

▶The newly-organized Electronics and Instruments Division of **Baldwin-Lima-Hamilton Corp.** will occupy a 102,000-sq. ft. factory at Waltham, Mass., upon its completion by September 1.

▶**Daystrom, Inc.,** announced retention of Robert LeBaron to assist it in expansion in the atomic energy field. The former deputy to the Secretary of Defense for Atomic Energy, now head of **LeBaron Associates,** will personally conduct studies for expansion of Daystrom's nuclear instrument line and will assist in development, manufacture and marketing of equipment for both military and commercial use.

▶**Landsverk Electrometer Co.,** 550 West Garfield Ave., Glendale, Calif., is completing a Navy contract for neutron dosimeters designed for personnel protection in the vicinity of reactors. The company's standard model L-29 has been designated by the military Radiacmeter IM-112/PD.

▶**Leeds & Northrup Co.,** Philadelphia, has been awarded a contract for the complete control system for the 1-Mw Livermore Pool-Type Reactor by **Foster Wheeler Corp.,** the prime contractor. The LPTR, to be operated for AEC by the University of California at Livermore Research Laboratory, is to be in operation by December.

▶Sales of **Sylvania Electric Products Inc.** in 1955 exceeded $300-million for the first time in the company's 54-year history. Sales "approaching the half-billion dollar mark" within the next 5–6 years were forecast.

▶R. S. Landauer Jr. & Co. have moved their film badge service to larger quarters at 24 Plaza, Park Forest, Ill.

▶The Manufacturing Chemists' Association has named three new technical and functional committees, one of which is an Atomic Energy Committee. Robert C. Swain of American Cyanamid Co. is serving as acting chairman.

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NEWSMAKERS

Allan E. Jones, deputy manager of AEC's Grand Junction, Colo., Operations Office, has been named manager. He succeeds **Sheldon P. Wimpfen,** who held the post since 1952 and who left to become vice-president of the Glen Alden Coal Co., Wilkes-Barre, Pa. He will remain an AEC consultant. The new manager joined AEC in 1952.

Frederick C. Gronemeyer of Fluor Corp., and **James C. Cochran** of AEC and the Navy Bureau of Ships, have joined the engineering staff of Atomics International division of North American Aviation.

Karl R. Van Tassel is manager of a newly-established Atomic Products Study in General Electric's Atomic Products Division, a project to determine production and marketing plans for commercial atomic products not now assigned to G.E.'s Atomic Power Equipment Department. Formerly general manager of Knolls Atomic Power Laboratory, he will be succeeded there by **Frederick E. Crever,** formerly manager of the Submarine Advanced Reactor project at KAPL.

GE also announced appointment of **Carl A. Bennett,** at Hanford since 1947, as manager of the Hanford operations research section. He succeeds **Benjamin F. Butler,** named to GE's management consultation services division in New York.

Sam Norris has been elected president of Nuclear Corporation of America, Inc. He is the first operating president of the company, formed last September.

AEC announced appointment of **Paul A. Wilson** as manager of the Los Alamos Field Office, succeeding **Frank C. DiLuzio,** who becomes assistant manager for production in the Albuquerque headquarters of Santa Fe Operations Office. This is a newly-created post for supervising, scheduling and coordinating manufacturing programs.

E. Eugene Fowler, chief of the allocations branch of the AEC Isotopes Division at Oak Ridge, is the new acting deputy director of the division succeeding **Charles E. Crompton,** whose departure to the National Lead Co. of Ohio was announced here last month.

Alfred N. Rogers is chief engineer of Baldwin-Lima-Hamilton Corp.'s newly-formed Nuclear Engineering Dept.

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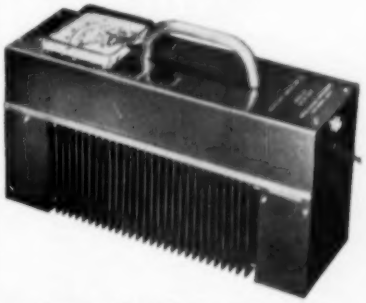

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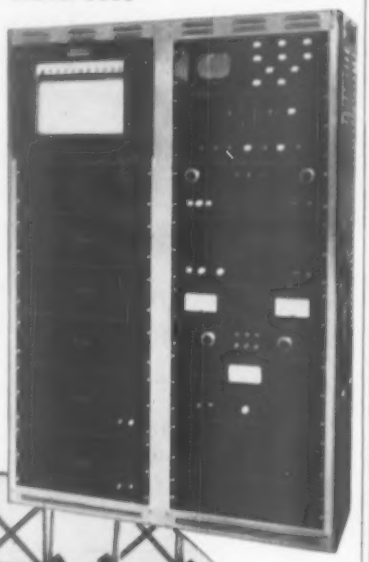

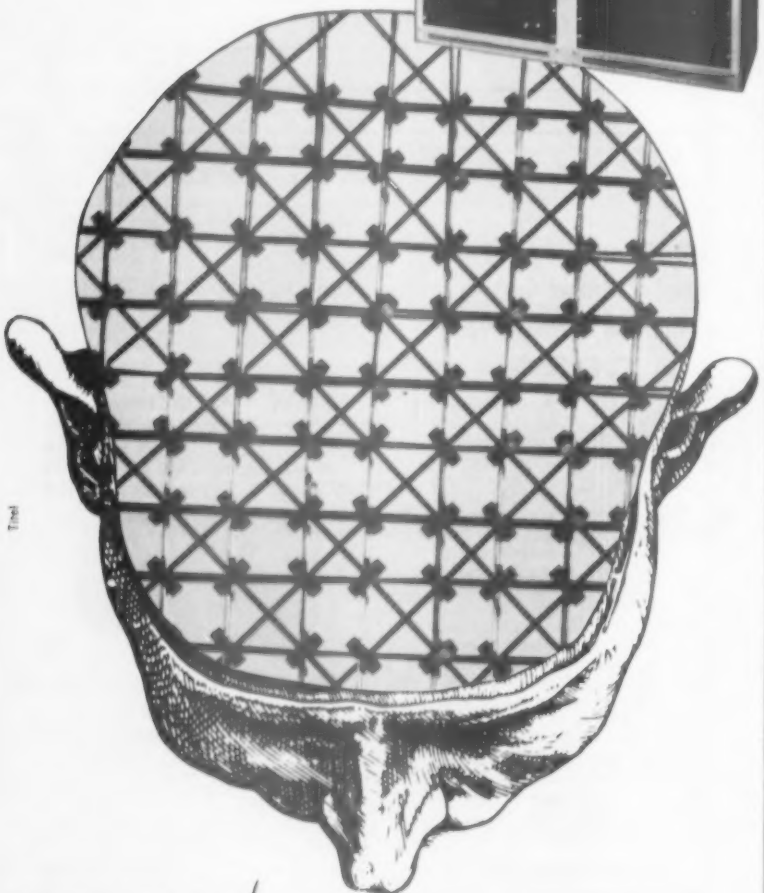

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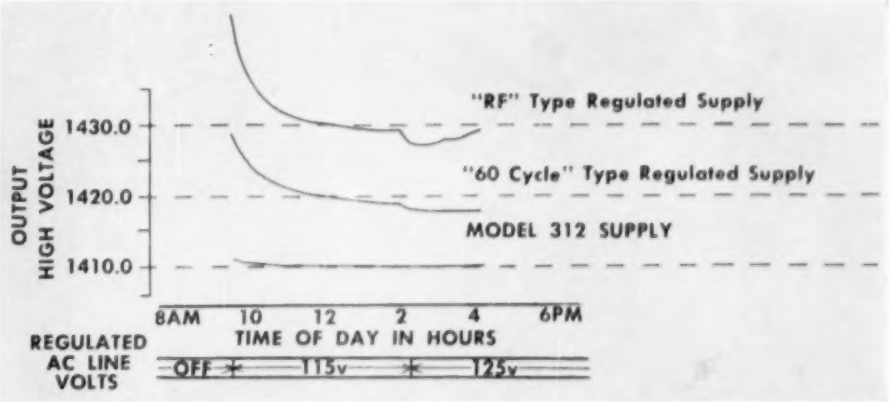

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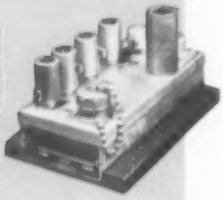

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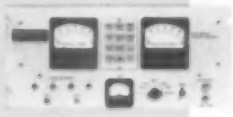

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